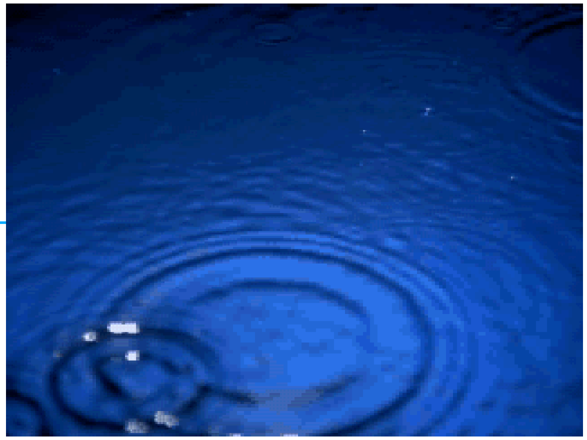
GPM

# Global Precipitation Measurement

## System Definition Review

## DPR Overview/Requirements



**December 6-8, 2005**

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*Goddard Space Flight Center*

# Overview

- *Changes since SRR*
- *Level 2 Requirements*
- *DPR Development Organization*
- *DPR Document Tree*
- *Mission Requirements for DPR*
- *DPR Performance Requirements*
- *DPR Functionality*
- *DPR On-Orbit Configuration*
- *Precipitation Measurement Concept*
- *DPR Scanning Concept*
- *KuPR and KaPR Block Diagram*
- *KuPR and KaPR Layout*
- *DPR Operational State Flow*
- *Calibration and assessing DPR state*
- *Interface Requirements*
- *Interface Design Status*
- *DPR Pre-development Phase work status*
- *Pictures of BBM and EM*
- *DPR Development Plan*
- *DPR Review Schedule*
- *DPR Schedule*
- *DPR Potential Risk and Issues*

# Changes Since SRR

- ***There have been no changes for the DPR Overview/Requirements since the SRR.***

# DPR Instrument Definition

## Level 1 Requirements

**Mission:**
* Measurement
* Validation
* Products
* Duration

**Instrument:**
* Space Based
* Ground Based

* Launch *Operations
*Science Data System
*Science Products
* Descope * Public Outreach

## Level 2 Requirements

**Science:**
* Storm Types
* Precip Types
* Measurements
* Coverage
* Frequency & Accuracy

**Mission:**
* Data Handling
* Payloads
* Constellation Design
* Calibration & Verification
* Outreach

* Launch Services * Process Requirements

**Space Segment:**
* Instruments
  - DPR
  - GMI
* Primary Spacecraft
  - Performance
  - Accommodation
* Constellation Spacecraft
  - Performance
  - Accommodation

**Ground Segment:**
* NASA Mission Operations
  - S/C Flight Ops
  - Space/ Ground Coordination
* Ground Validation & Calibration
  - Super Site
  - Regional Rain Gauge Network
* Precipitation Processing System
  - Product Development
  - Data Distribution

## Other Sources

* Formulation Study Results
* Science Workshops
* GSFC Guidelines

NICT Input

PR Heritage

## Instrument Level 2 Requirements:

- Mission Science, including the detection of rain & snowfall
- Measurement Channels
- Interface Requirements
- Lifetime
- Reliability
- Operating Bands
- Horizontal/Vertical Resolution
- Swath Width
- Data Allocation
- Calibration
- DPR Algorithms

## Instrument Level 3 Requirements

***GPM DPR***

***Instrument Specification***

***JX-ESPC-100079***

***And GPM Core Observatory to DPR ICD***

NICT JAXA

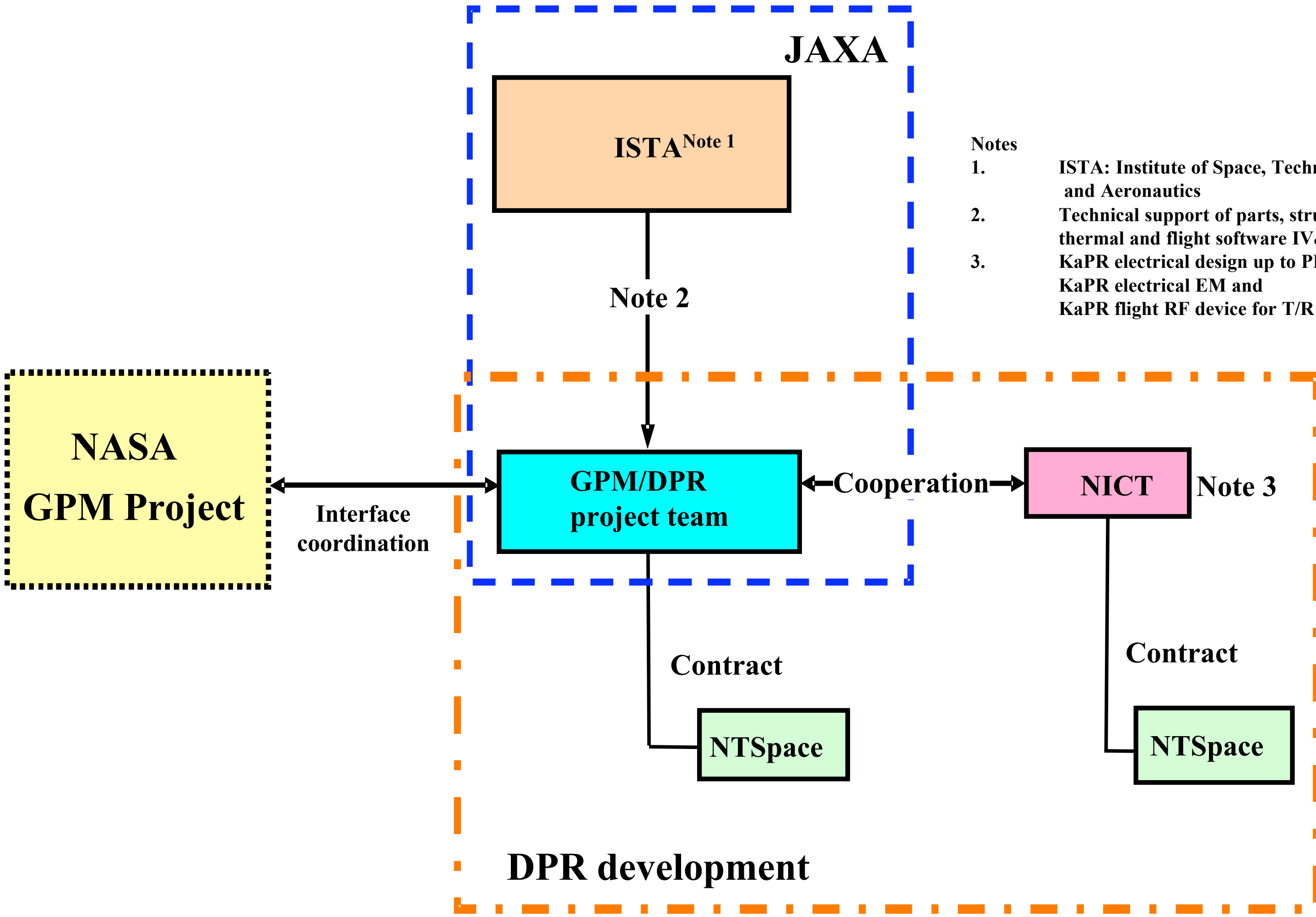
# Level 2 Requirements for DPR

- **Level 2 Requirements for DPR**
  - *(4.1.1) DPR Interface Requirement-DPR requirements for mechanical, electrical, and thermal interfaces, as well as environmental requirements and constraints shall be specified in the GPM Core Spacecraft Observatory to Dual frequency Radar (DPR) Interface Control Document.*
  - *(4.1.2) DPR Lifetime-The DPR shall be designed to operate for 3 years, after a 60-day on-orbit checkout period.*
  - *(4.1.3) DPR Reliability-The KaPR shall have a Ps of greater than 0.85 over the mission lifetime. The KuPR shall have a Ps of greater than 0.85 over the mission lifetime.*
  - *(4.1.4) Operating Bands-The DPR shall make measurements in both Ku and Ka frequency bands. The KuPR radar frequencies shall be 13.597 GHz, 13.607 GHz (two frequency agility). The KaPR radar frequencies shall be 35.547 GHz, 35.553 GHz (two frequency agility).*
  - *(4.1.5) Horizontal Resolution-The DPR shall have horizontal resolution of 5 Km.*

# Level 2 Requirements for DPR (continued)

- *(4.1.6) Vertical Resolution-The DPR shall have vertical resolution of 250 m at Ku and 250/500 m at Ka.*
- *(4.1.7) Swath Width- The Ku-PR shall have a swath width of at least 240 km from an altitude of 407 km. The Ka-PR shall have a swath width of at least 115 km from an altitude of 407 km.*
- *(4.1.8) DPR Data Allocation- The DPR shall deliver no more than 190 kbps of continuous average data rate to the spacecraft bus, with no more than an additional 2 kbps as housekeeping data.*
- *(4.1.9) Calibration-The radar reflectivity factors measured by the KuPR and KaPR shall be calibrated to within an accuracy of $\pm$ 1 dBZ.*
- *(7.2.19) DPR Algorithms-The PPS shall receive all Level-1 and above DPR instrument science algorithms from JAXA for incorporation into the general processing stream.*

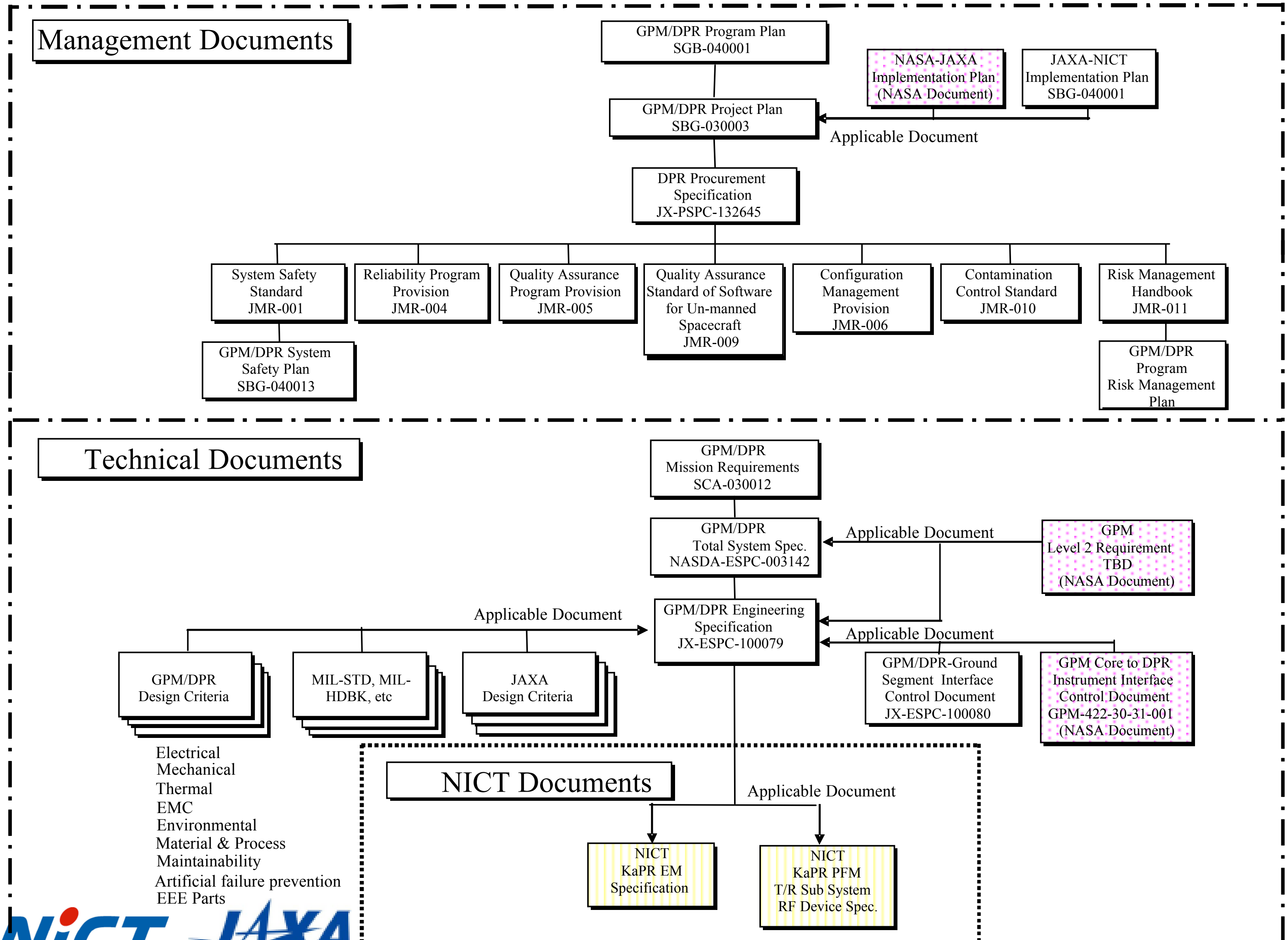
# DPR Development Organization




Notes

1. ISTA: Institute of Space, Technology and Aeronautics
2. Technical support of parts, structure, thermal and flight software IV&V
3. KaPR electrical design up to PDR, KaPR electrical EM and KaPR flight RF device for T/R module

# JAXA DPR Document Tree



# Example of DPR Level 2 Requirements Flowdown

- ## *4.1.7 Swath Width*

  *The Ku-PR shall have a swath width of at least 240 km from an altitude of 407 km. The Ka-PR shall have a swath width of at least 115 km from an altitude of 407 km.*

### *DPR Level 3 Requirement:*

– *KuPR (13.6 GHz) shall have a swath width of 245 km @ 407 km*

– *KaPR (35.5 GHz) shall have a swath width of 120 km @ 407 km*

### *Sensitivity Calculation of KaPR:*

- *Z (S/N=1 for 1 pulse, res=250 m) = 22.4 dBZ*
- *Z (S/N=1 for 1 pulse, res=500 m) = 16.4 dBZ*

| Swath width | N of beams | Obs. Time /beam | N of pulses | Effective S/N(dB) | σ (dB) | 3σ S/N(dB) | Min dBZ | Rain (mm/h) Ze=200R^1.6 | Min dBZ | Rain (mm/h) Ze=200R^1.6 |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Range res. = 250 m | | Range res. = 500 m | |
| 5 km | 1 | 714.3 ms | 4470 | 14.0 | 0.092 | -16.3 | 6.1 | 0.053 | 0.1 | 0.004 |
| 40 km | 8 | 89.3 ms | 558 | 9.5 | 0.256 | -11.1 | 11.3 | 0.185 | 5.3 | 0.078 |
| 100 km | 20 | 35.7 ms | 224 | 7.5 | 0.397 | -8.5 | 13.9 | 0.270 | 7.9 | 0.114 |
| 245 km | 49 | 14.6 ms | 68 | 5.0 | 0.696 | -4.4 | 18.0 | 0.486 | 12.0 | 0.205 |

(For the matched beam condition, refer to SW=245 km.)

(Number of noise samples is 4 x N)

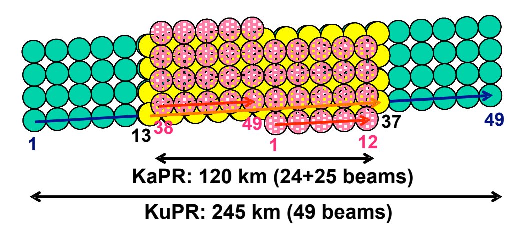
Assumptions:

- H = 400 km (ΔH=10 km)
- Beam width = 0.71 degree
- Range res. = 250 m/500 m
- Log detection
- 2-freq. agility

- Tx power = 144 W
- Rx noise = -110.0 dBm
- Feed Loss = 1.5 dB
- Filter Loss = 1.3 dB

### *Concept of the DPR antenna scanning method*

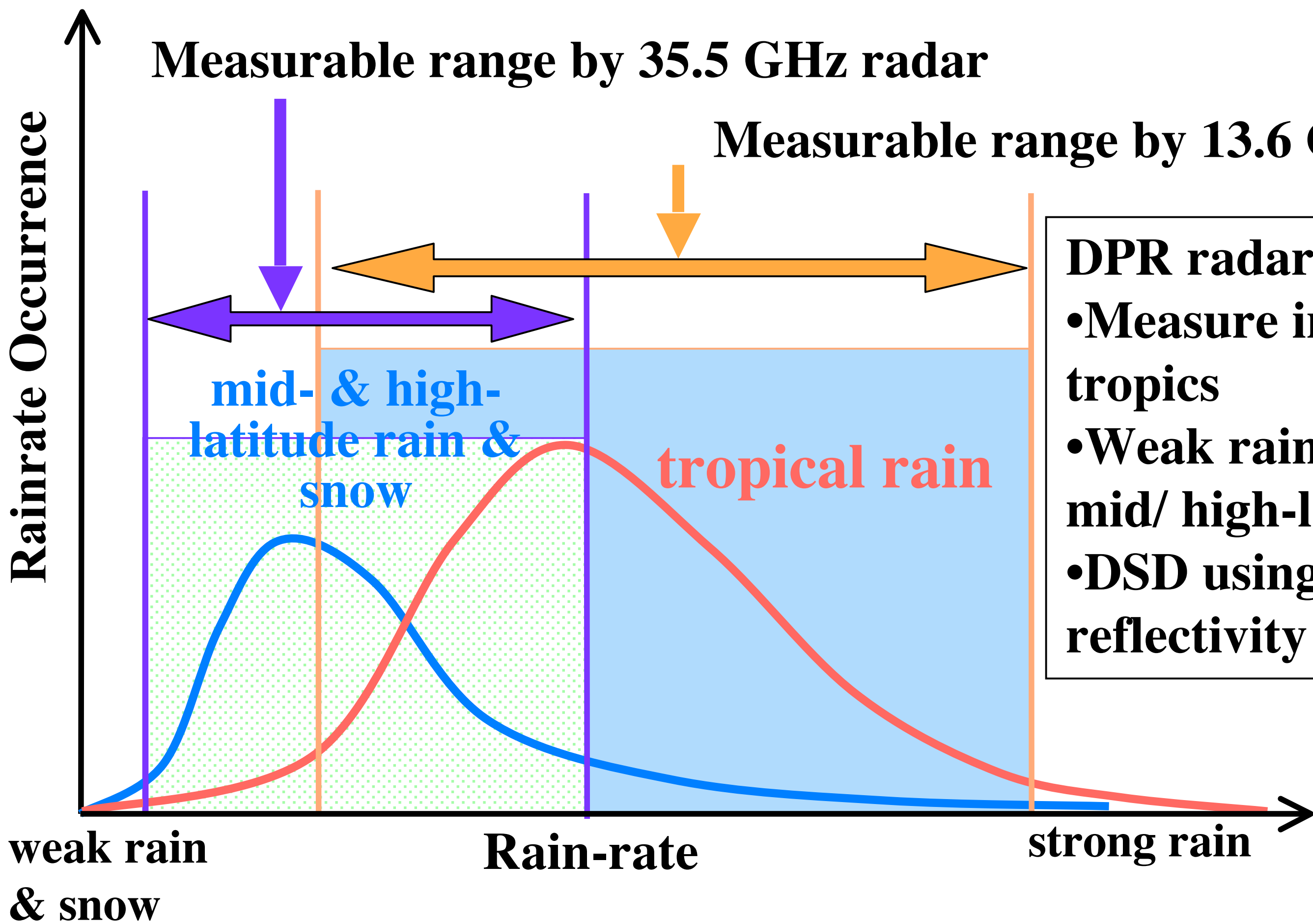
- KuPR footprint : Δz = 250 m
- KaPR footprint (Matched with KuPR) : Δz = 250 m
- KaPR footprint (Interlaced) : Δz = 500 m



# DPR Performance Requirements

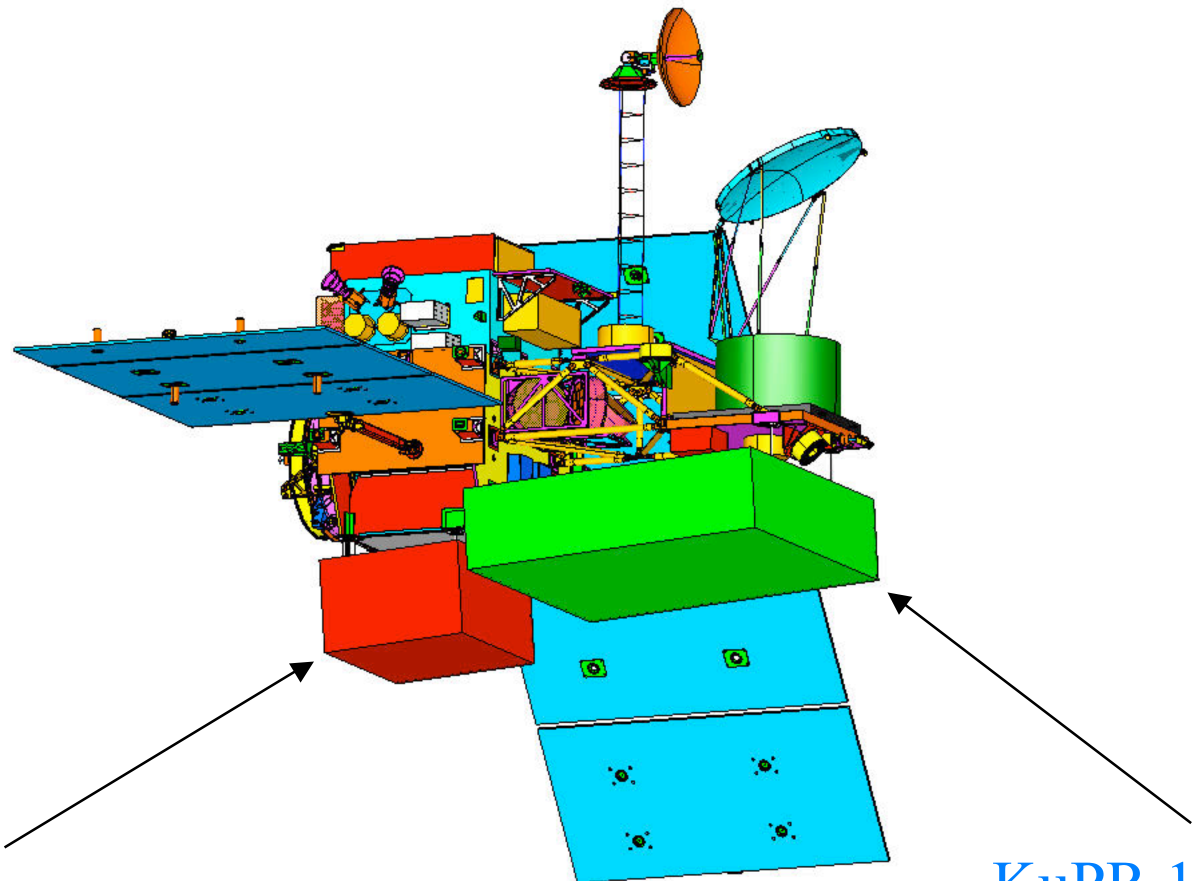
| Item | **KuPR** | **KaPR** |
|---|---|---|
| Center frequency | 13.6 GHz | 35.55 GHz |
| Range resolution<br>Pulse width | 250 m<br>Equal to or less than 1.67 ms | 250/500 m<br>Equal to or less than 1.67/3.34 ms |
| Horizontal resolution (at nadir)<br>Half-power beam width (at nadir) | 5 km<br>0.71 deg. +/- 0.02 deg. | 5 km<br>0.71 deg. +/- 0.02 deg. |
| Swath width | Above or equal to 245 km | Above or equal to 245 km (range resolution 250 m)<br>Above or equal to 115 km (range resolution 500 m) |
| Minimum detectable rainfall rate | 0.5 mm/h | 0.5 mm/h (range resolution 250 m)<br>0.2 mm/h (range resolution 500 m) |
| Beam matching error | Equal to or less than 1000 m | |
| Observation range | -5 to 18 km (mirror image at nadir) | -3 to 18 km (mirror image at nadir) |
| Averaged number of independent samples | Above or equal to 96 | Above or equal to 96 |
| Dynamic range | Above or equal to 70 dB | Above or equal to 70 dB |
| Measurement accuracy | Within +/- 1 dB | Within +/- 1 dB |
| Data rate | Within the 108.5 kbps allocation | Within the 81.5 kbps allocation |
| Power consumption | Within the 384 W allocation | Within the 326 W allocation |
| Mass | Within the 450 kg allocation | Within the 330 kg allocation |
| Size | Be able to stow in the rocket fairing when DPR is attached to the spacecraft | |
| Geolocation knowledge | Less than or equal to 1/2 pixel, 2.5 km | |
| Geolocation accuracy | Less than or equal to 1 pixel, 5.0 km | |
| Pointing stability | Less than or equal to 0.6 arcmin over 1 sec. interval | |

JAXA/NICT Dual Frequency (13.6, 35.55 GHz)
Ku and Ka Band Precipitation Radar




**DPR radar will:**
- **Measure intense rain in tropics**
- **Weak rain & snow in mid/ high-latitudes**
- **DSD using differential reflectivity**

# DPR On-Orbit Configuration

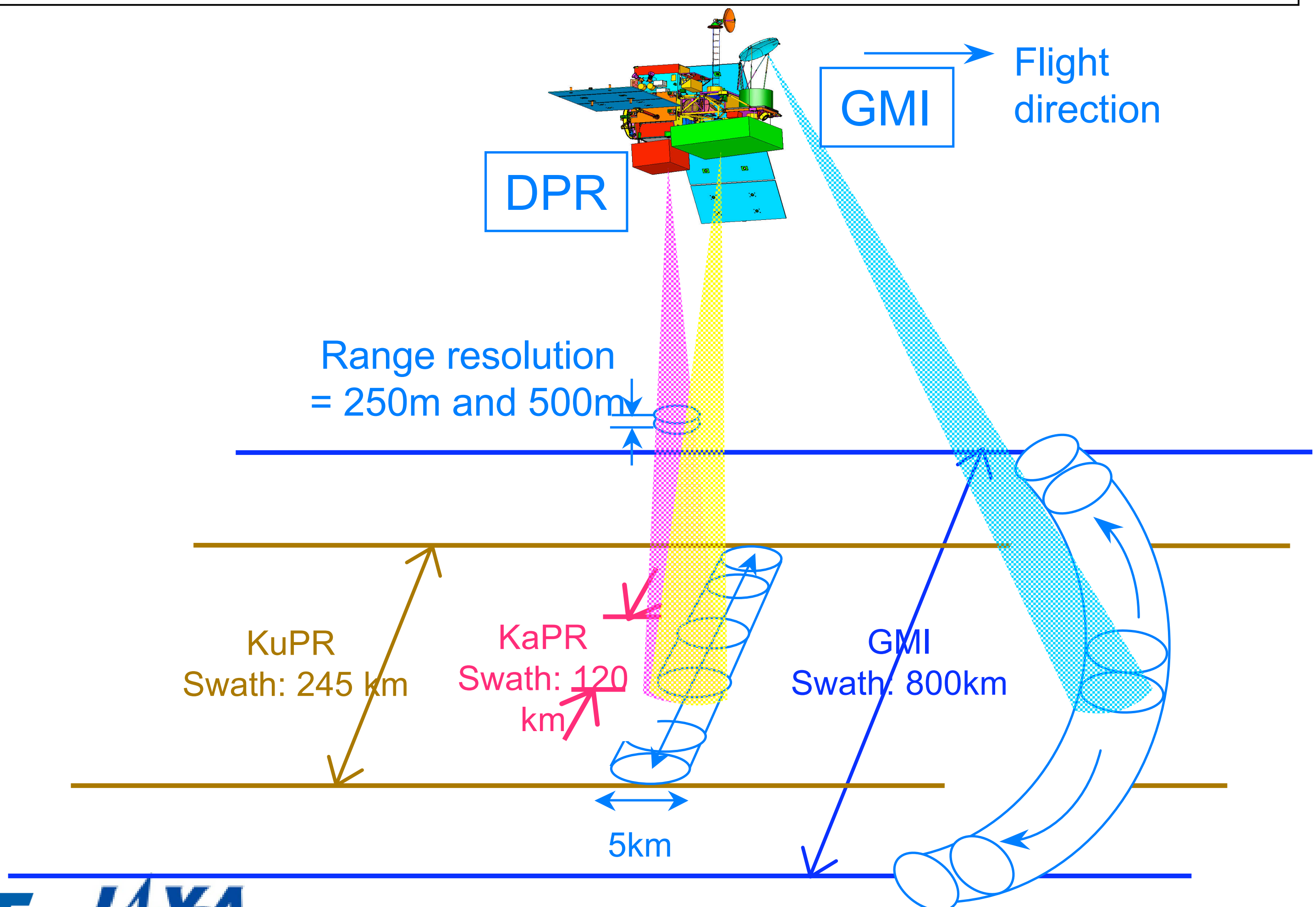


KaPR 35.5GHz radar (Active phased array)

KuPR 13.6GHz radar (TRMM PR type, active phased array)

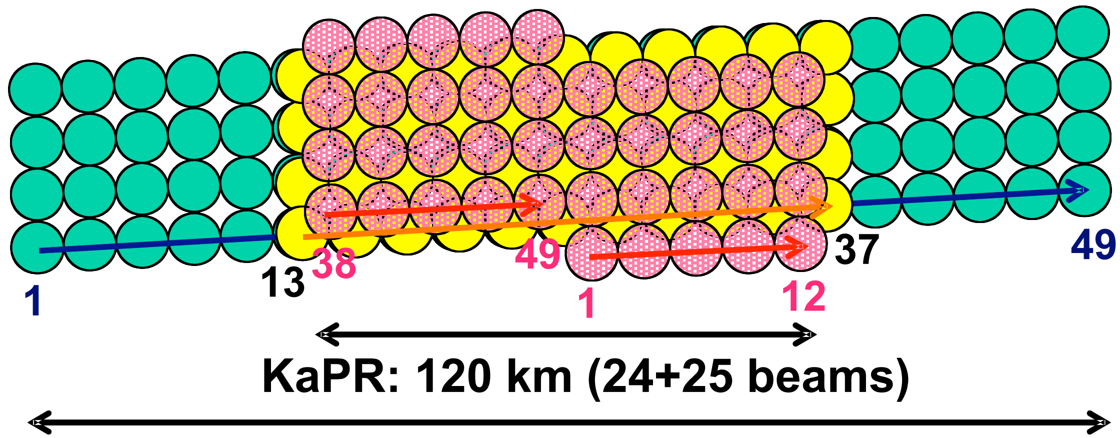
# Precipitation Measurement Concept

**Dual-frequency precipitation radar (DPR) consists of Ku-band (13.6GHz) radar : KuPR and Ka-band (35.5GHz) radar : KaPR**



# Concept of the DPR antenna scanning method

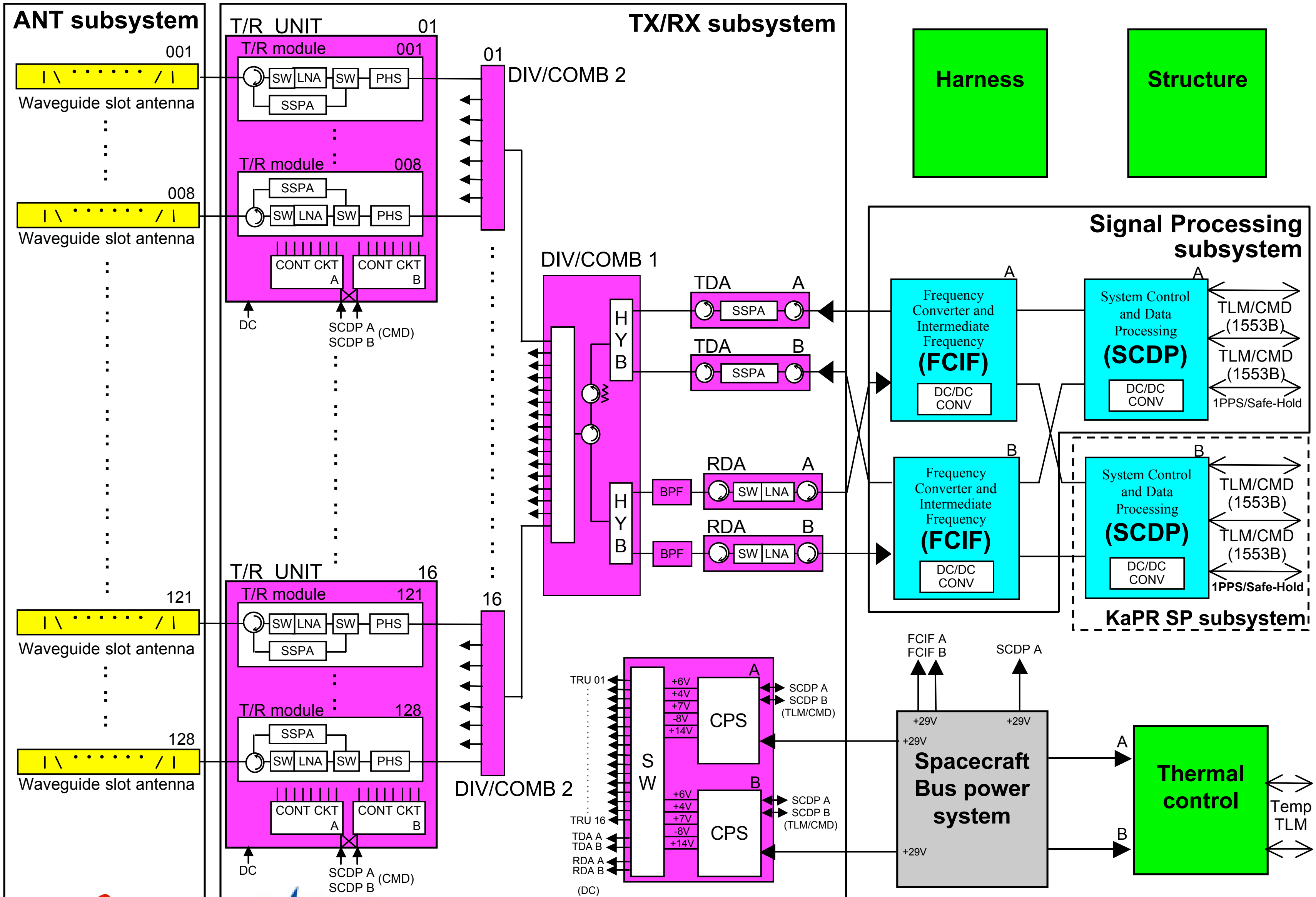
- KuPR footprint : $\Delta z = 250$ m
- KaPR footprint (Matched with KuPR) : $\Delta z = 250$ m
- KaPR footprint (Interlaced) : $\Delta z = 500$ m



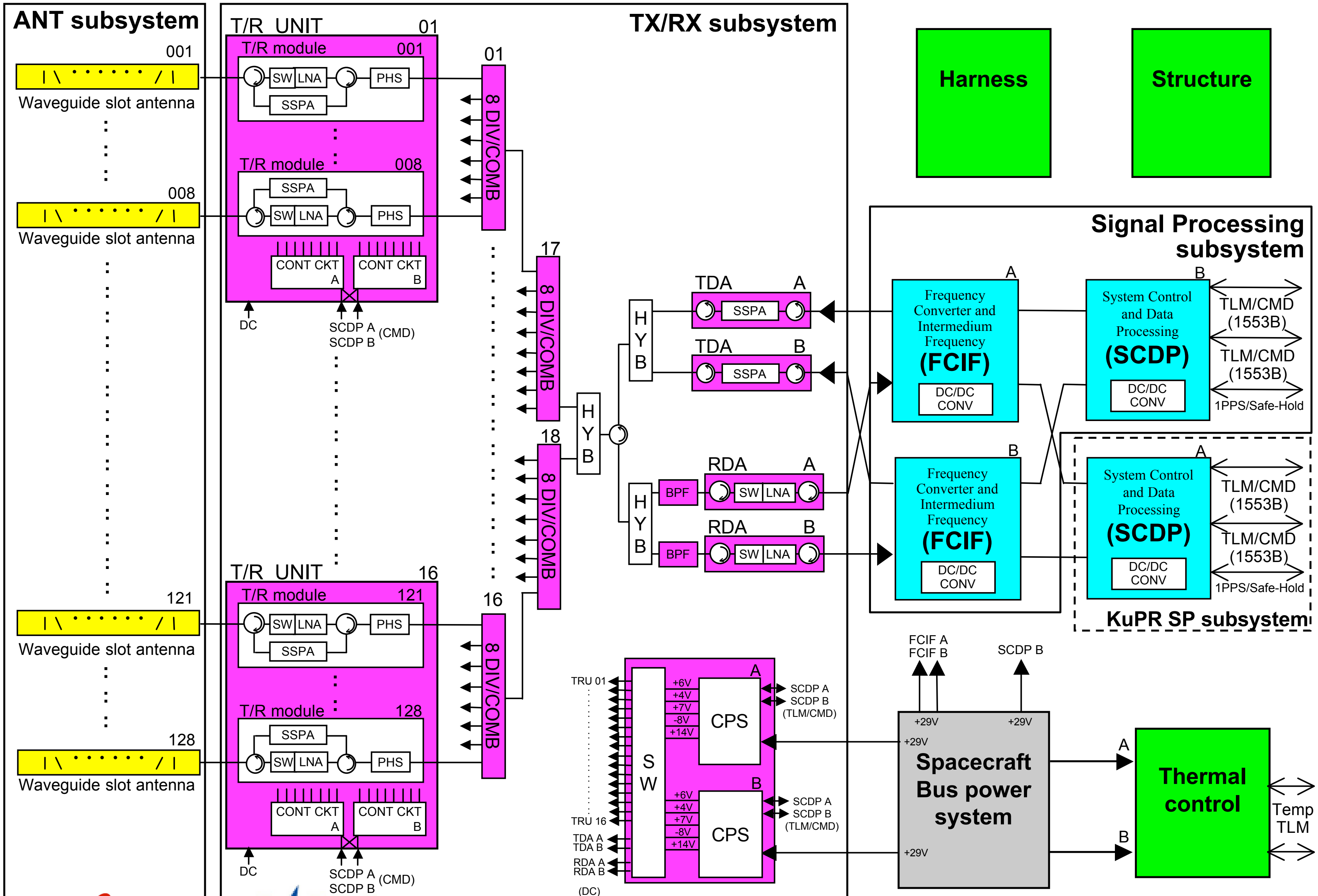

In the interlacing scan area (●), the KaPR can measure snow and light rain in a high-sensitivity mode with a double pulse width.

The synchronized matched beam (●) is necessary for the dual-frequency algorithm.

# KuPR Block Diagram



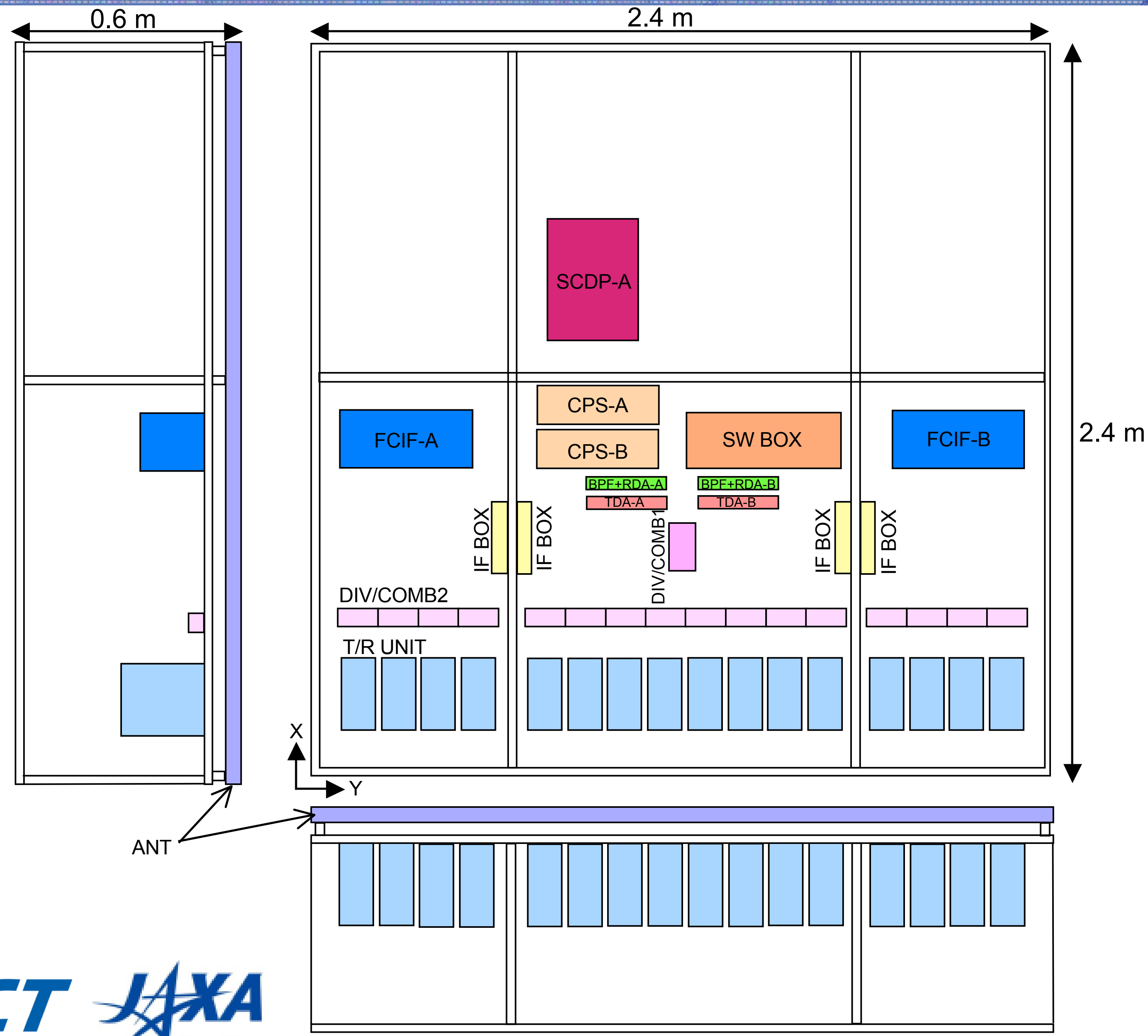
# KaPR Block Diagram



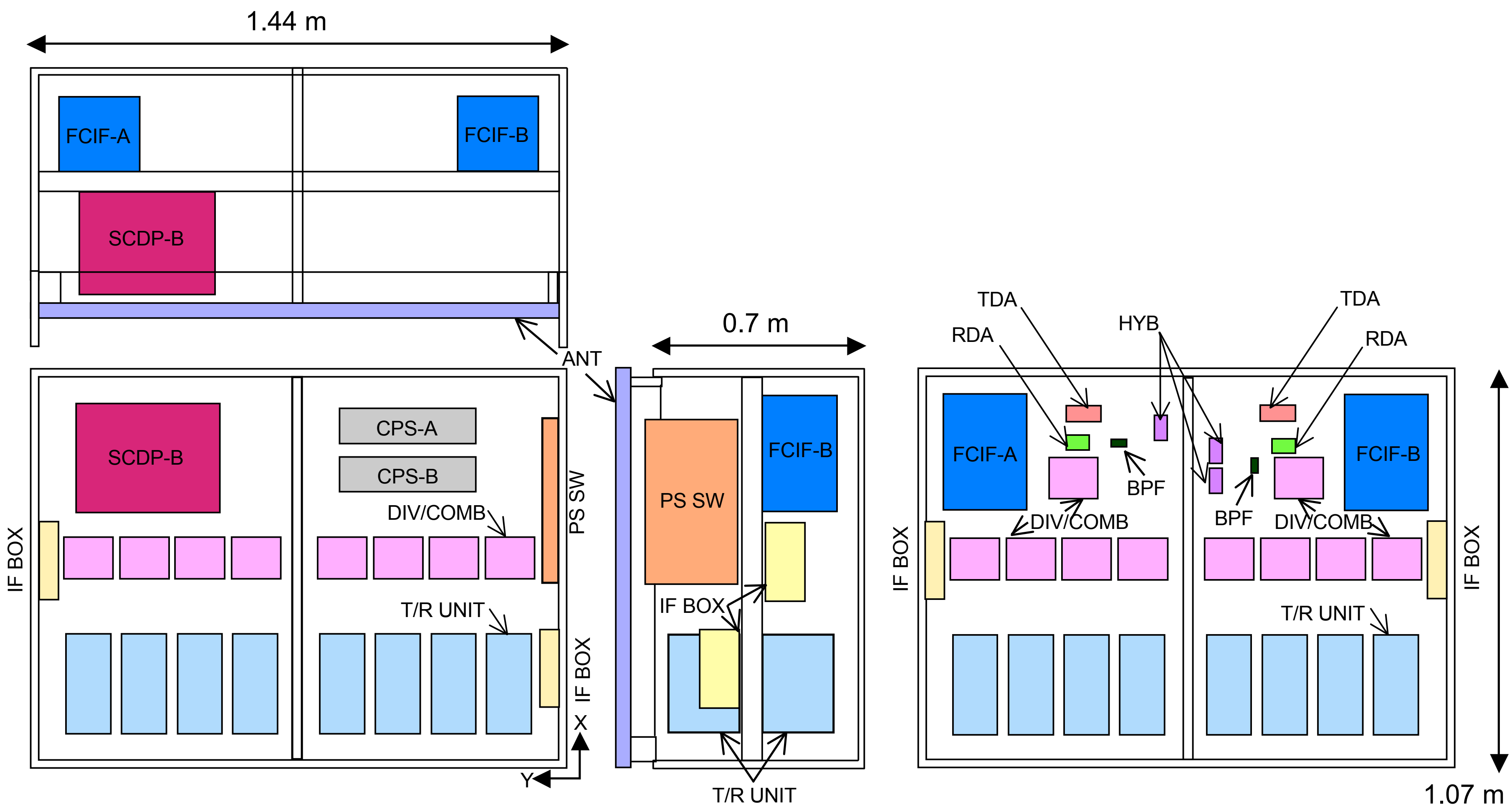

GPM

G L O B A L P R E C I P I T A T I O N M E A S U R E M E N T

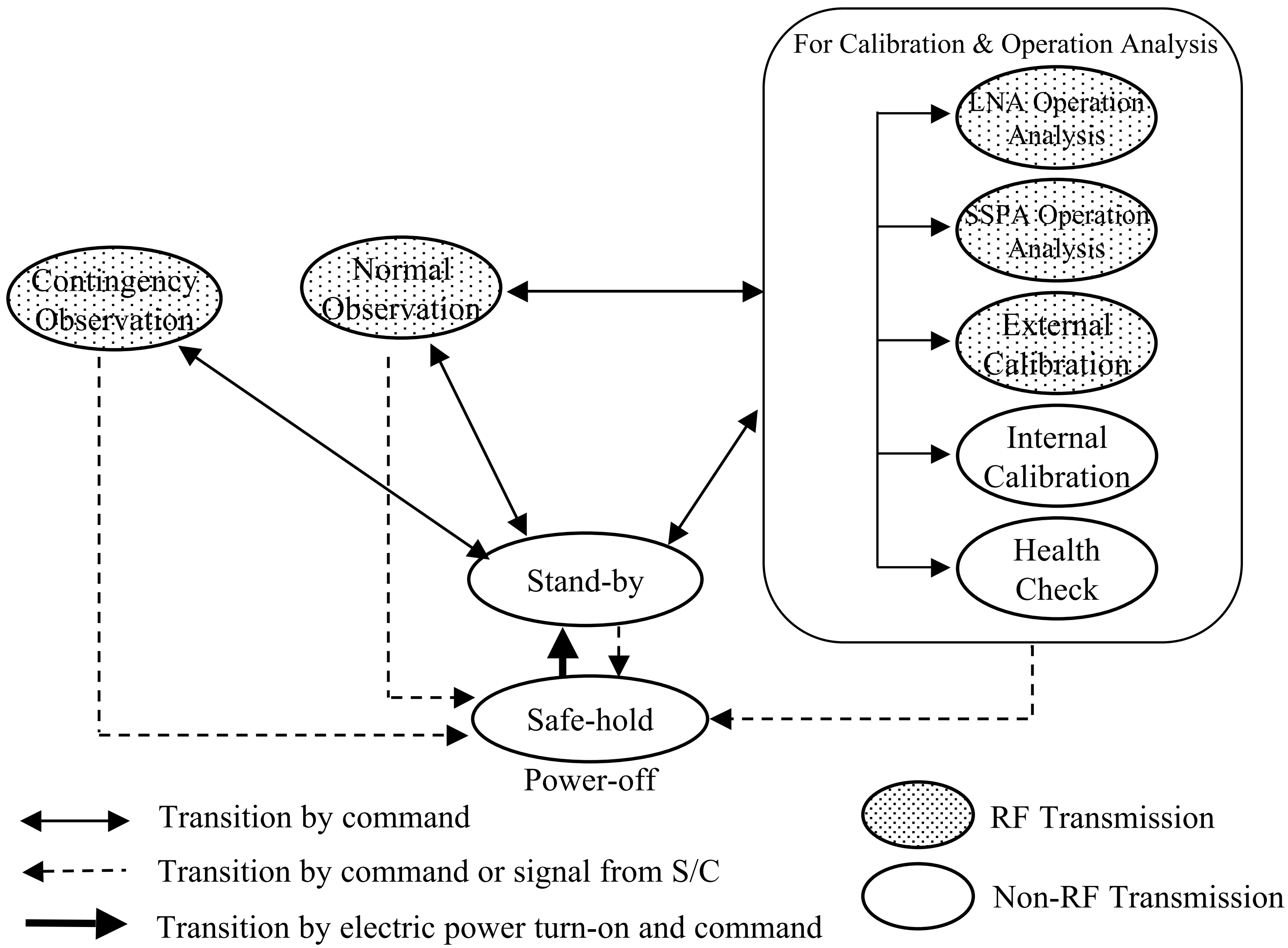
# KuPR Layout


0.6 m
2.4 m
2.4 m
SCDP-A
CPS-A
CPS-B
FCIF-A
SW BOX
FCIF-B
BPF+RDA-A
BPF+RDA-B
TDA-A
TDA-B
IF BOX
IF BOX
DIV/COMB1
IF BOX
IF BOX
DIV/COMB2
T/R UNIT
X
Y
ANT

# KaPR Layout


1.44 m
FCIF-A
FCIF-B
SCDP-B
ANT
SCDP-B
CPS-A
CPS-B
DIV/COMB
PS SW
IF BOX
T/R UNIT
IF BOX
X
Y
0.7 m
PS SW
FCIF-B
IF BOX
T/R UNIT
TDA
RDA
HYB
TDA
RDA
FCIF-A
BPF
BPF
FCIF-B
DIV/COMB
DIV/COMB
IF BOX
IF BOX
T/R UNIT
1.07 m

# DPR Operational State Flow



# Calibration and Assessing DPR State

## DPR :continuous operational mode except for calibration and checking modes in the following table

| Mode | | Frequency | Location | Duration |
|---|---|---|---|---|
| ***calibration*** | External | about twice a year | Over ARC (=Active Radar Calibrator) at Tsukuba (36.07N, 140.13E) | 5 minutes |
| | Internal | about once a month | Over ocean where it's not raining so much or Where the signal needs to be stopped to avoid the interference with other sites | 2 minutes |
| ***checking*** | LNA | about once a month or when the current monitor shows any anomaly | Over ocean where it's not raining so much | 3 minutes |
| | SSPA | | | |

**For assessing DPR health, safety, and long-term performance**

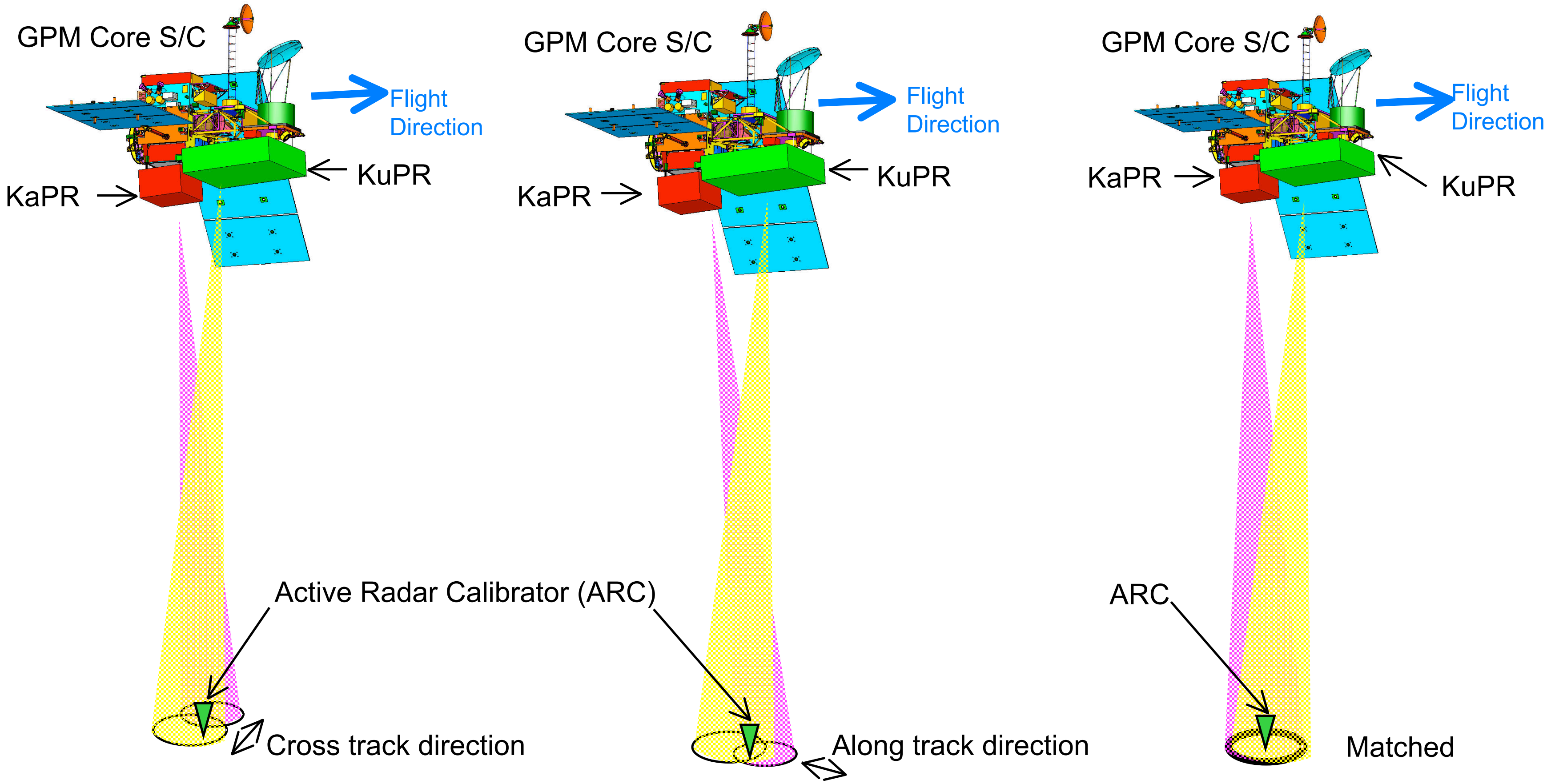
| *item* | *parameters* | *Data source* |
|---|---|---|
| *Temperature* | *Antenna panel, SCDP, FCIF, RF Unit* | *HK telemetry* |
| *SSPA/LNA* | *Current level monitors* | *Science telemetry* |
| *Receivers & Radio Interference* | *System noise* | |
| *VPRF* | *GPS altitude, Surface echo peak position, VPRF table* | |
| *Long-term DPR performance* | *Surface cross section (ocean, no rain)* | |

GPM

# Beam Matching On-Orbit Adjustment and Validation

GLOBAL PRECIPITATION MEASUREMENT

**Cross track direction beam shift** | **Along track direction beam shift** | **Matched beam**




After measuring beam positions by Active Radar Calibrator (ARC),
- Cross track direction : adjust the beam direction changing phase shifter control.
- Along track direction : set delay for one radar system.

# Interface Requirements

- ***Draft ICD between DPR and Core Observatory***
  - *Defines the following interface requirements for DPR and for Core Spacecraft*
    - *Mass, power, data rate and volume*
      - *Parameters discussed earlier*
    - *Spacecraft altitude variation range to be 397 – 419km (Geodetic altitude from ellipsoid)*
    - *1553 B data bus to transmit DPR data and commands*
    - *GPS altitude data and time code (delivery via 1553 B data bus)*
    - *1 Hz timing signal*
    - *Hardline Power Off Warning Signal (dedicated line)*
    - *Thermal interface definition*
    - *DPR to Spacecraft Mechanical interface*
      - *Kinematics mount to the S/C bus with 4 deg. cant angle*
      - *Natural frequency requirements*
      - *DPR design limit load, mechanical environment, factors of safety*
    - *DPR to Spacecraft Electrical Interface*
      - *Power (Redundant and Cross-strapped service) defined-29 Vdc(±6Vdc)*
      - *Electrical Harness between radars*
    - *DPR co-alignment requirement (KuPR and KaPR beam alignment) to be less than 1km*
    - *DPR geolocation knowledge and accuracy requirements to be less than _ pixel and 1 pixel respectively*

# Interface Design Status

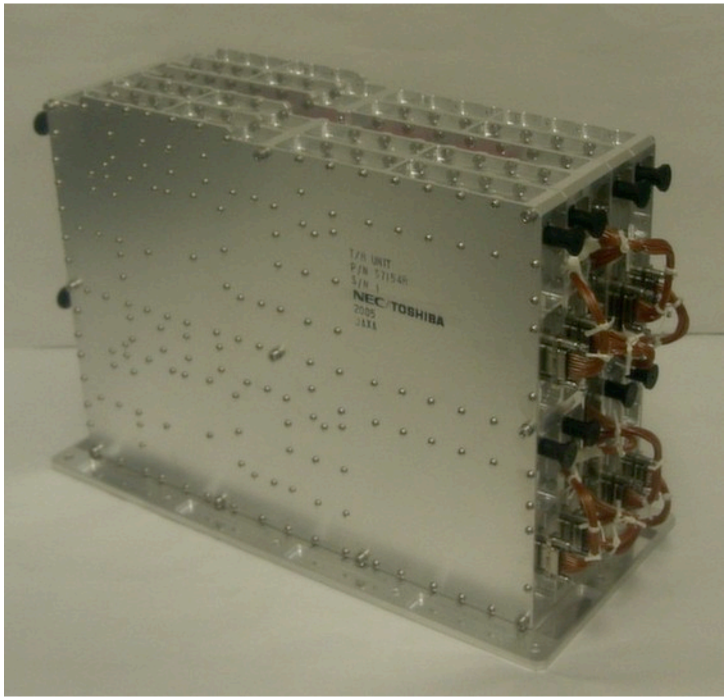
| Interface item | DPR interface design status |
|---|---|
| Orbit interface | VPRF design proceeding based on 397-419km geodetic altitude from ellipsoid |
| Mass | KuPR : ICD req.≦450kg, current estimate is 435.8kg<br>KaPR : ICD req.≦330kg, current estimate is 319.9kg<br>Meets req. but will continue to investigate further mass reduction alternatives. |
| Power | KuPR : ICD req.≦384W, current estimate is 366.6W<br>KaPR : ICD req.≦326W, current estimate is 310.2W<br>DPR total power estimate meets req. |
| Science data rate | KuPR : ICD req.≦108.5kbps, current estimate is 108.5kbps<br>KaPR : ICD req.≦81.5bps, current estimate is 81.5kbps<br>DPR total science data rate meets req. |
| Mechanical interface | Comply with requirements.<br>Structural design study under way to avoid very high local panel response induced by sine vibration input. |
| Thermal interface | Radiation area increased to keep sufficient temperature margin.<br>Use S/C thermal math model for radiative heat transfer interface. Assume no conductive heat transfer between S/C and DPR. |
| Electrical interface | Design proceeding based on interface condition. |
| Telemetry & command interface | Design proceeding based on interface condition. |
| Co-alignment & geolocation interface | Preliminary estimate satisfies req.<br>Error budget allocation between S/C and DPR under way. |

# DPR Pre-Development Phase Work Status

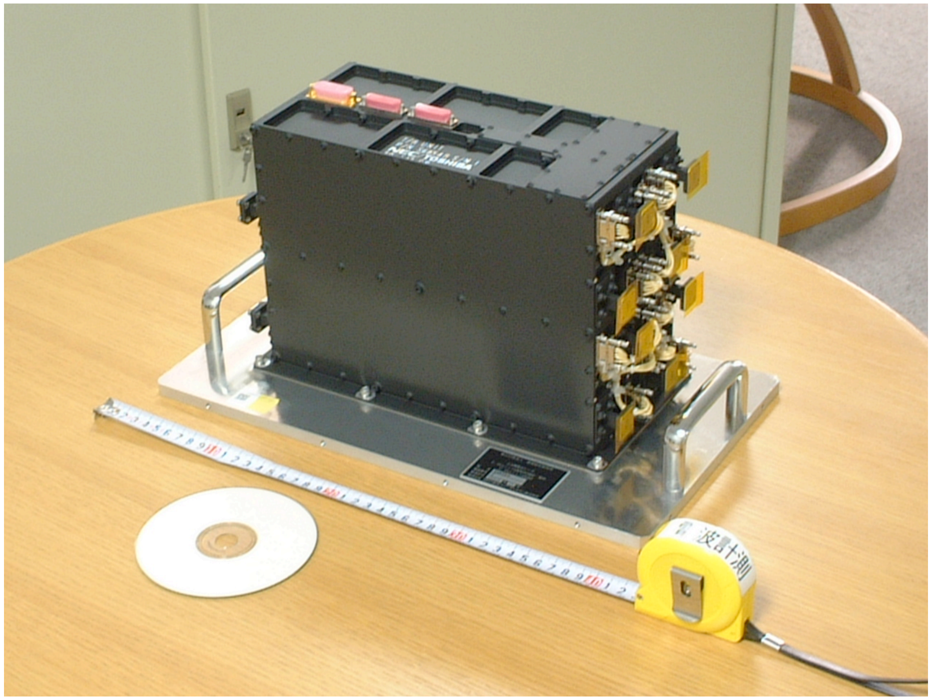
| | Concept | Need to develop/study | Note |
|---|---|---|---|
| *Antenna BBM* | *TRMM/PR type but lighter weight*<br>*(128 elements)* | *Half thick waveguide slot antenna*<br>*White paint thermal shock test* | *KuPR : completed*<br>*KaPR :completed*<br>*→Electrically conductive white paint thermal shock test is planned.* |
| *T/R UNIT BBM* | *8 T/R modules*<br>*2 electrical models*<br>*6 thermal dummies* | *HIC, MMIC, MCM, and integration* | *KuPR : completed*<br>*→ Design of 32 elements EM will be started from next January.*<br>*KaPR :completed*<br>*→ Fabrication 32 elements EM is underway.* |

# KuPR and KaPR BBM

## KuPR BBM (1 T/R Unit)

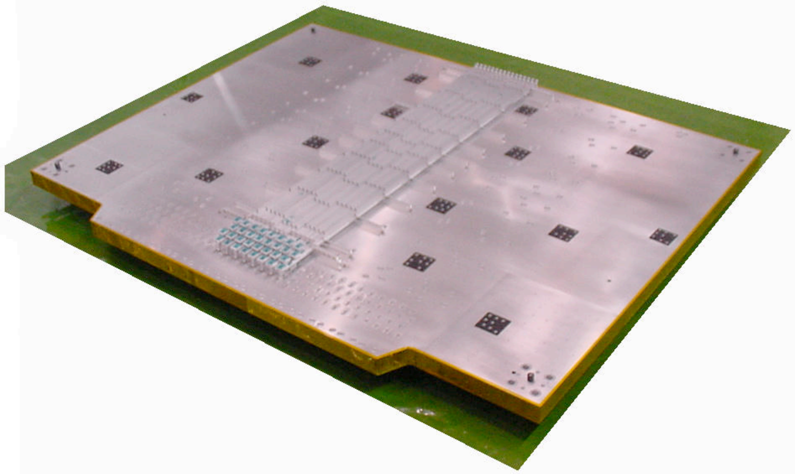


## KaPR BBM (1 T/R Unit)

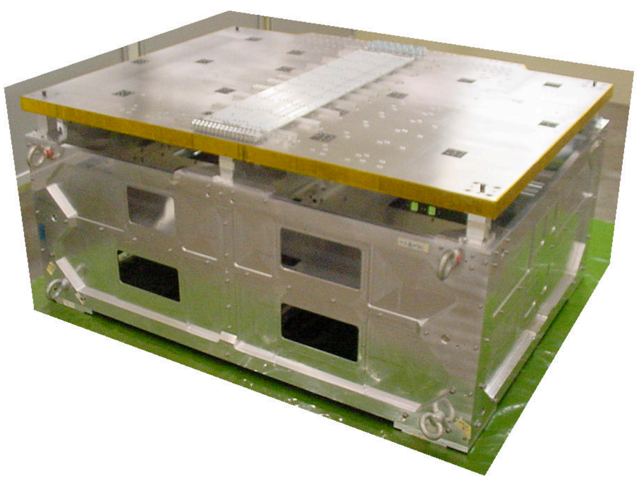


# Components of KaPR EM

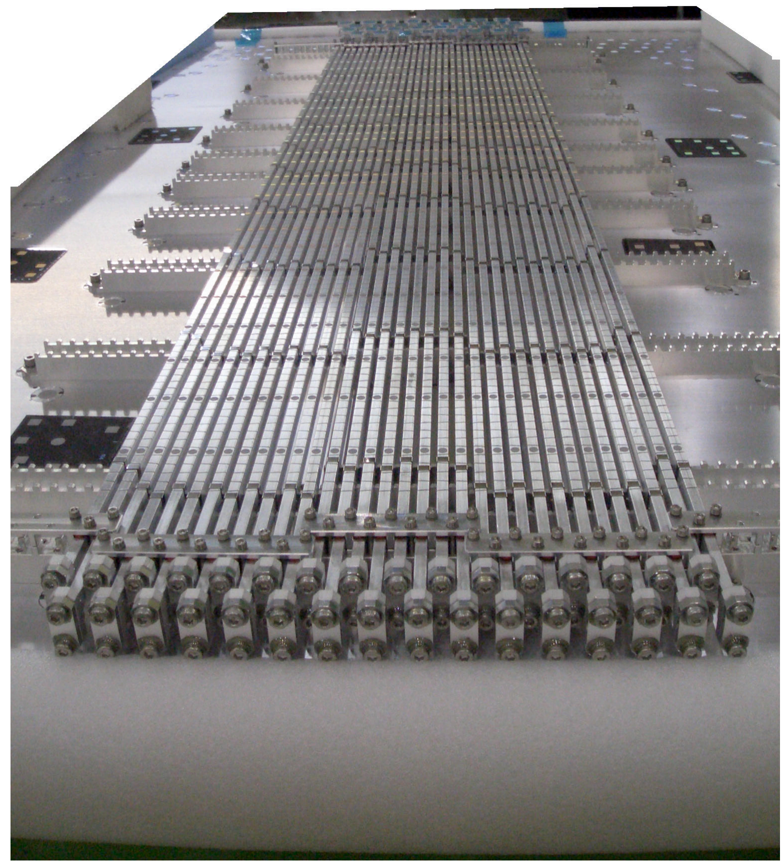
KaPR EM Antenna Panel



KaPR EM



KaPR EM Antenna Close-up



# DPR Development Plan (KuPR)

| | Development model | Purpose of the development model | Content of the development model |
|---|---|---|---|
| KuPR | T/R UNIT BBM | ・Verification of the basic electrical performance and clarification of the issues. | ・T/R unit consists of 8 T/R modules. ・Regarding BBM, 6 T/R modules are thermal dummy |
| | 32 element EM(*) | ・Components qualification test ・Verification of KuPR operation and basic electrical performance ・Verification of the DPR operation connecting KuPR & KaPR EMs | ・All type of SSPA included ・Cross track antenna pattern is different from PFM ・No redundancy |
| | STM(*) | ・Verification of the KuPR structural and thermal design ・Verification of the components mechanical environment | ・Mechanical and thermal design and manufacturing process is the same as the PFM |
| | PFM | ・PFM for launch | ・Flight model satisfying engineering specification requirements |

* Regarding KuPR, 32 element EM and STM is the same physical model

# DPR Development Plan (KaPR)

| | Development model | Purpose of the development model | Content of the development model |
|---|---|---|---|
| KaPR | T/R UNIT BBM | ・Verification of the basic electrical performance and clarification of the issues. | ・T/R unit consists of 8 T/R modules.<br>・Regarding BBM, 6 T/R modules are thermal dummy |
| | 32 element EM | ・Components qualification test<br>・Verification of KaPR operation and basic electrical performance<br>・Verification of DPR operation connecting KuPR & KaPR EMs | ・All type of SSPA and LNA included<br>・Cross track antenna pattern is different from PFM<br>・No redundancy |
| | STM | ・Verification of the KaPR structural & thermal design<br>・Verification of the components mechanical environment | ・Mechanical and thermal design and manufacturing process is the same as the PFM |
| | PFM | ・PFM for launch | ・Flight model satisfying engineering specification requirements |

# DPR Development Plan (Supplemental Testing)

- ***DPR antenna panel white paint testing***
  - *Thermal shock test*
  - *Irradiation test of AO, ultraviolet rays and electron beam*

- ***Electric discharge verification test in vacuum environment for KuPR and KaPR***
  - *Find out electrical discharge critical portion by analysis regarding antenna and TX/RX subsystem*
  - *Perform electrical discharge test in vacuum environment by manufacture test sample which is the same as PFM*

- ***T/R unit life test for KuPR and KaPR***
  - *Use T/R unit EM*
  - *Temperature accelerated life test to check degradation of the electrical performance*

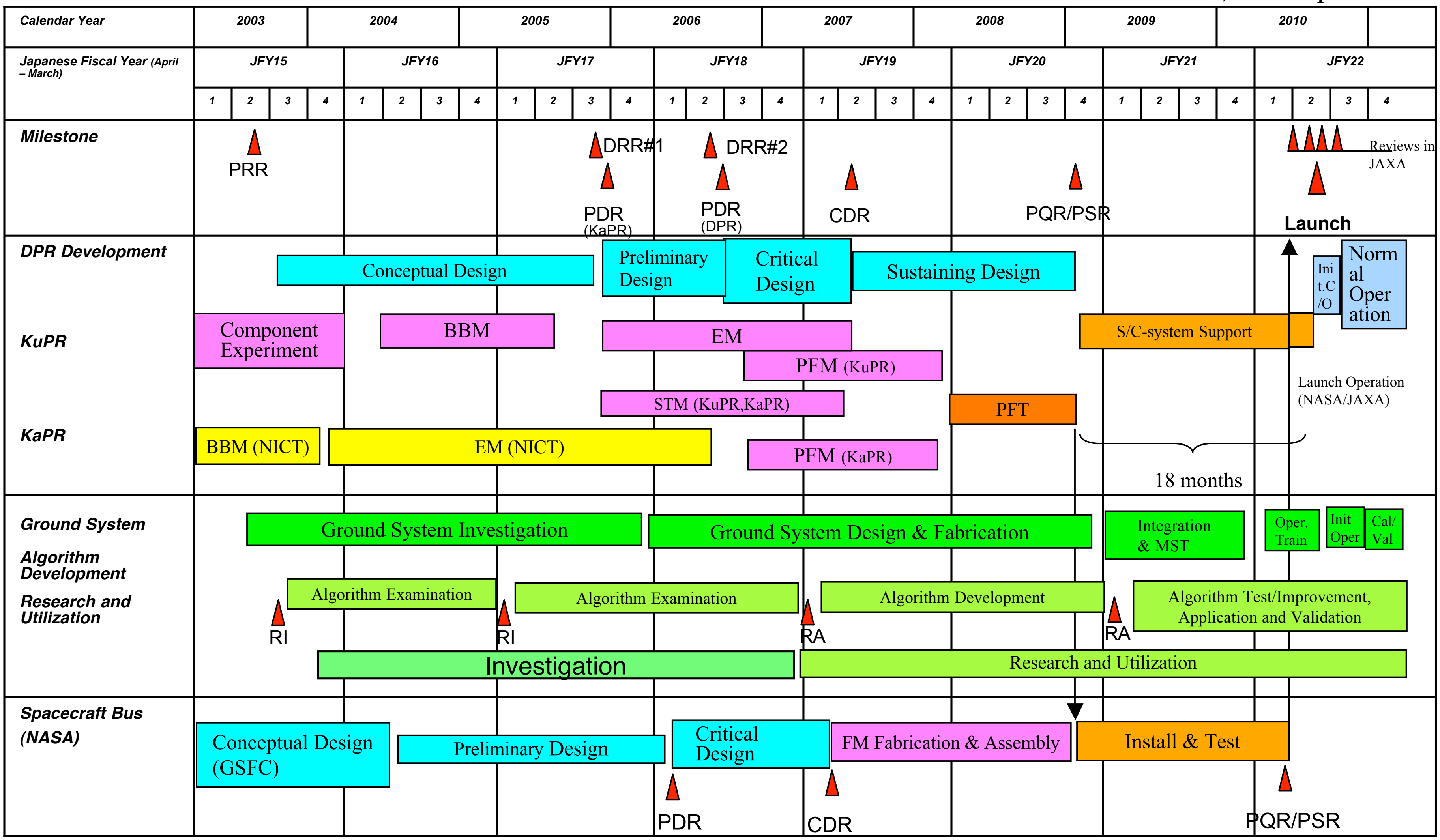
# DPR Review Schedule

- ***Milestone Reviews*** ***(NASA will attend the Interface Design Review)***
  - *Development Readiness Review #1 in JAXA (2005.12)*
  - *KaPR Preliminary Design Review in NTSpace (2005.12)*
  - *Development Readiness Review #2 in JAXA(2006.8)*
  - *Preliminary Design Review in NTSpace (2006.9)*
  - *Interface Preliminary Design Review in NTSpace (2006.9)*
  - *Critical Design Review in NTSpace (2007.7)*
  - *Interface Critical Design Review in NTSpace (2007.7)*
  - *Post Qualification-test Review / Pre-Shipment Review in NTSpace (2009.1)*
  - *Interface Post Qualification-test Review / Interface Pre-Shipment Review in NTSpace (2009.1)*

- ***Review by Space Activities Commission***
  - *Phase-up Review to Phase C/D by SAC (2006.6)*

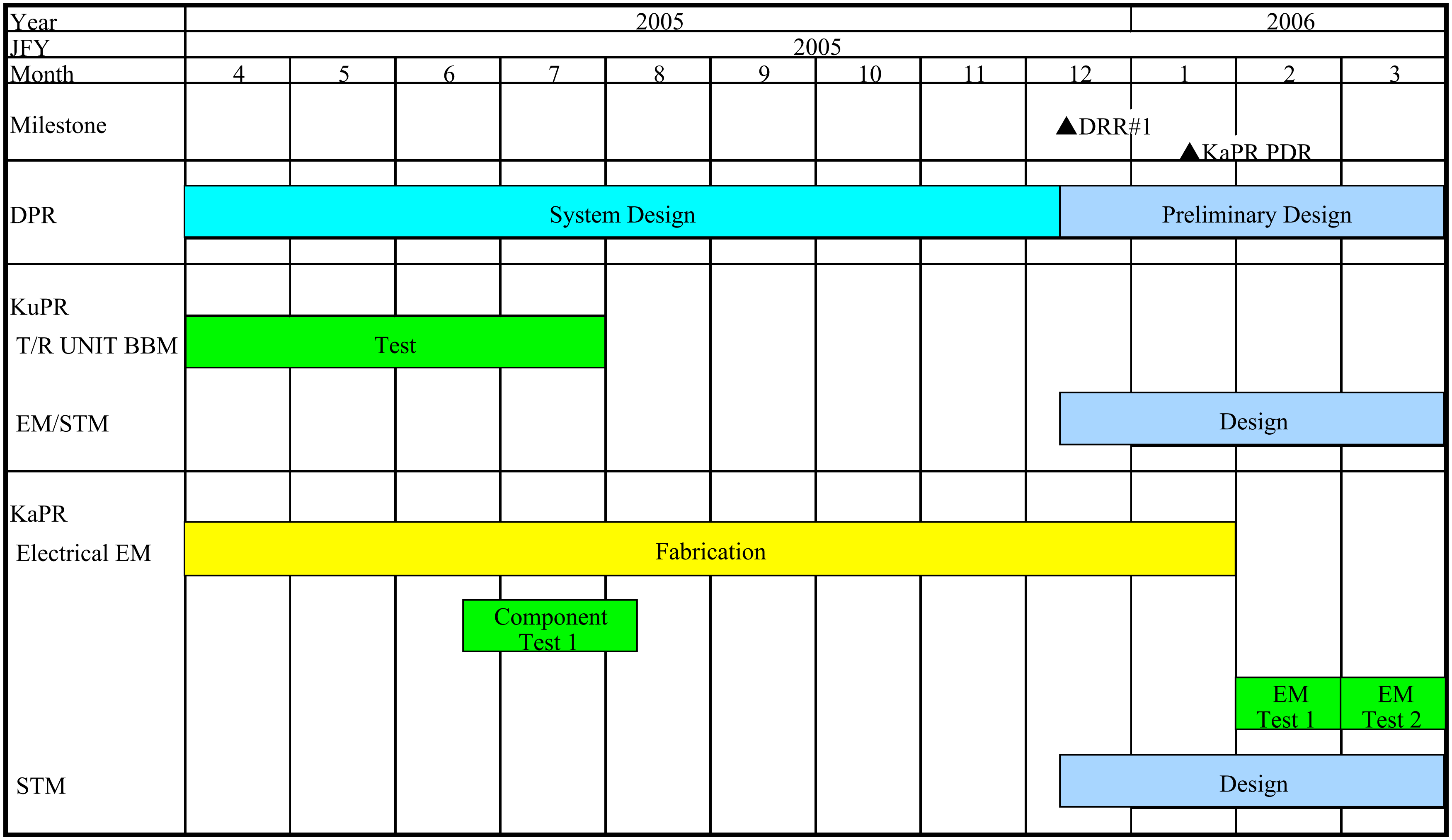
# DPR Top Level Schedule

Oct. 18, 2005 update




PRR: Project Readiness Review, DRR: Development Readiness Review, PDR: Preliminary Design Review, CDR: Critical Design Review, PFT: Proto Flight Test, PQR: Post Qualification-test Review, PSR: Pre-Shipment Review, MST: Mission Simulation Test

# DPR Near Term Schedule




EM TEST1：Function & Performance Test in ambient condition (RF link)

EM TEST1：Function & Performance Test in thermal vacuum condition (Hardline)

## DPR potential risk items

| L/N | DPR potential risk items | Mitigation |
|---|---|---|
| 1 | DPR and GMI interference verification test can not be performed by EM. Risk may be carried to the PFM phase. | To verify sufficient margin in component EMC test.<br>To check the spectrum of the EM output signal.<br>To perform DPR system level EMC test and GMI interference test in the early phase of the PFT.<br>Close coordination with NASA. |
| 2 | Delay of the DPR development schedule due to the manufacturing 256 T/R modules (128 for KuPR, and 128 for KaPR). | Make best use of the EM manufacturing experience and take appropriate action, such as improving the schedule control method, preparing sufficient number of the manufacturing line and skilled workers, etc. |

# DPR Potential Risk Items and Issues (2/2)

## DPR issues

| L/N | Issues | Mitigation |
|---|---|---|
| 1 | Countermeasures to keep DPR mass within allocation & strict mass control | Discuss with NASA about increasing DPR mass allocation. Investigate further mass reduction alternatives and associated risks. |
| 2 | Study about single failure point in PSSW | Investigate alternative design which avoids single failure point. Make trade-off study between current design and the alternative design. Study about more careful management of the single failure point in the current design. |
| 3 | Selection of thermal control materials such as antenna white paint, outer layer of MLI, etc. (AO resistant, electrically conductive, etc.) | Thermal shock test and AO/UV/electron irradiation test for new electrically conductive white paint. Study about the impact induced by electrically non-conductive white paint and the effect when electrically conductive white paint comes off. Consistency with spacecraft side design. |
| 4 | Development of the method to measure KaPR TX/RX amplitude and phase distribution due to the difficulty of attaching and detaching test divider/combiner. (Diameter of the KaPR waveguide is very small) | Verification of the new method using KaPR EM. (To cover the slotted area of the antenna by aluminum plate or film, remove the antenna termination and connect measurement equipment). Study other alternatives in case that the new method does not work well. |
| 5 | Sufficient verification of the on-board flight software | IVV of the flight software. Test plan to cover all the cases in S/W stand-alone level, SCDP component level, KuPR/KaPR system level, and DPR system level testing. Test plan to cover the maximum timing error tolerance. Long time operation test. |

# Back-Up Charts

# DPR Development Basic Policy

- ***Basic policy***
  - *Achievement of the mission requirements*
  - *Secure & reliable development*

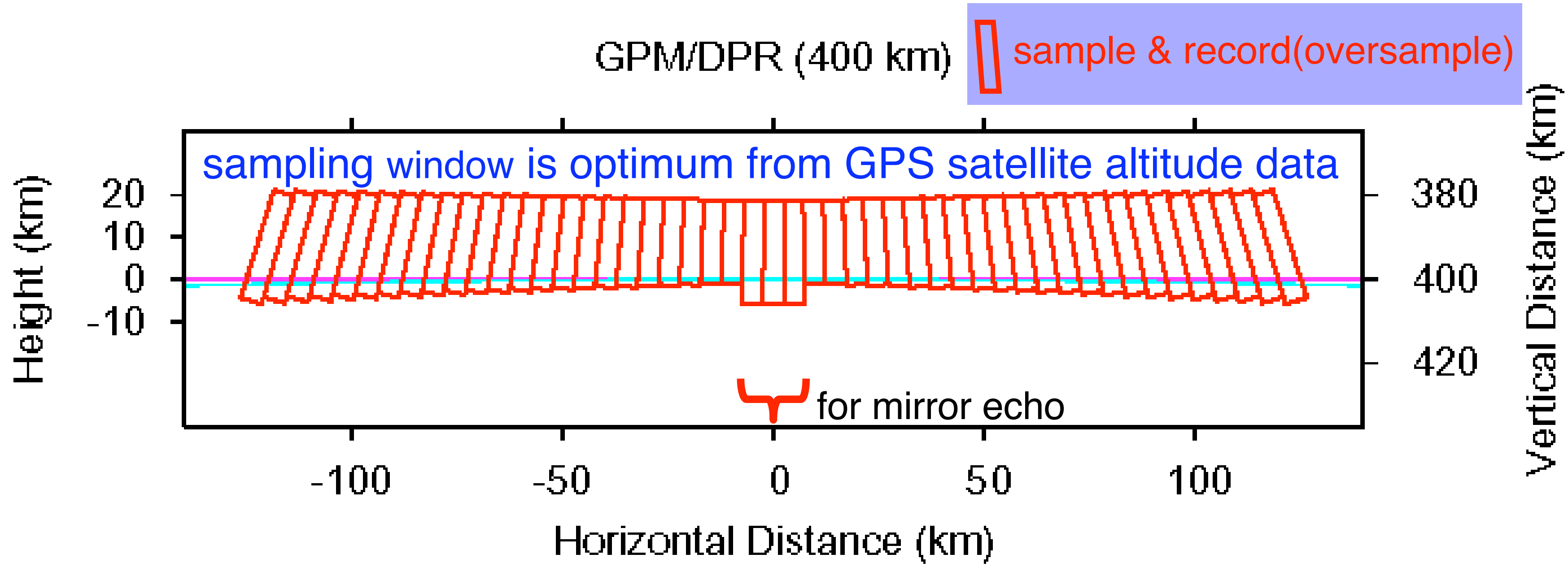
    - *To securely reflect mission requirements into DPR engineering specification*
    - *To reflect improvements learned through TRMM PR on-orbit operation into DPR engineering specification*
    - *To make maximum use of the TRMM PR development experience*
    - *To develop DPR as a unified system*
    - *Further reliability improvement*
      - *Identification and prevention of single failure point, redundancy, survivability, sufficient ground test and verification, end-to-end test, sufficient milestone review, sufficient reliability analysis such as FTA, FTA and FMEA*
    - *Step-by-step development plan and schedule*
    - *To be careful about consistency between NASA and JAXA technical requirements*

# JAXA (Level 3) Mission Requirements for DPR

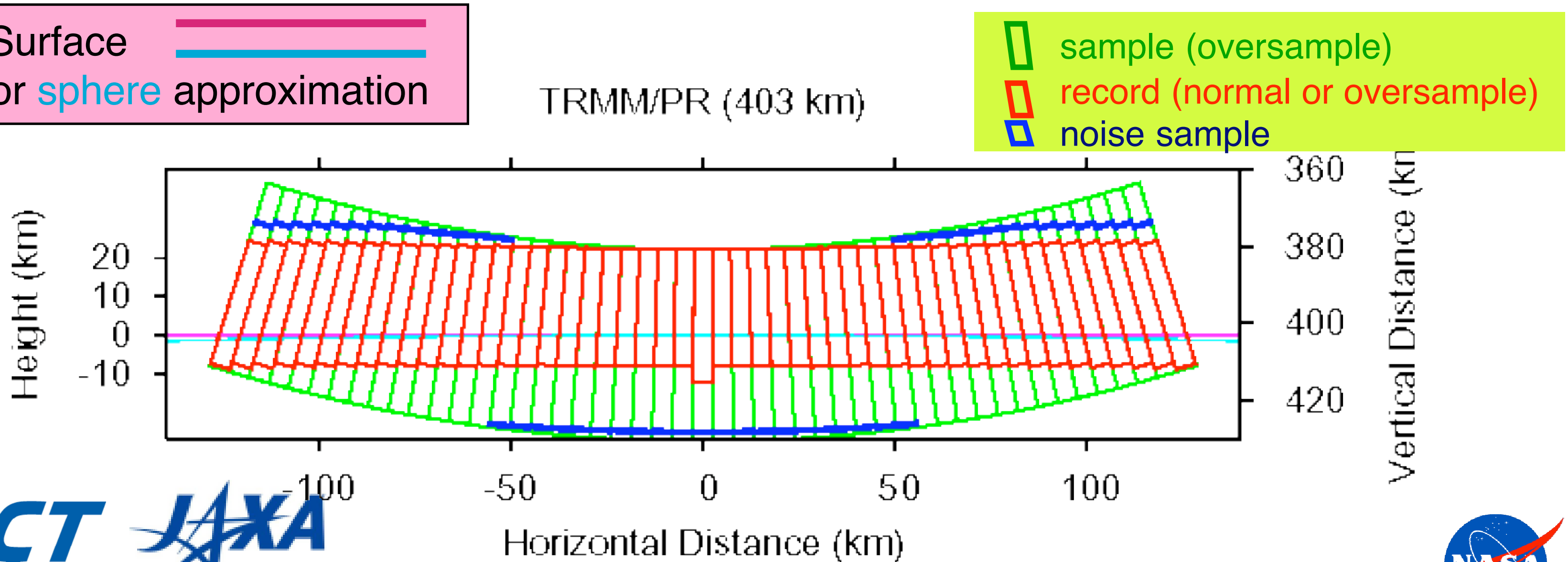
- ***Function Requirements for DPR***
  - *DPR shall observe 3-Dimensional structure of global precipitation including snow and rain with high precision.*
  - *DPR shall consist of Ku-band precipitation radar (KuPR) and Ka-band precipitation radar (KaPR).*
  - *KuPR shall observe heavy rainfall in the tropical region.*
  - *KaPR shall observe light rainfall and snowfall in the high latitude region.*
  - *KuPR and KaPR shall have the same foot print locations to generate dual-frequency radar observation (Beam matching).*
  - *Dual-frequency radar observation data shall be used in dual-frequency precipitation algorithm to discriminate of rain and snow, estimate of drop size distribution and estimate more accurate precipitation.*
- ***Parameters of Performance Requirements for DPR***
  - *Center frequency, Range resolution, Horizontal resolution, Swath width, Minimum detectable rainfall rate, Beam matching error, Dynamic range, Received power accuracy, Data rate, Power consumption, Mass and Size*

⇒ ***DPR Engineering Specification and ICD meet these all requirements.***

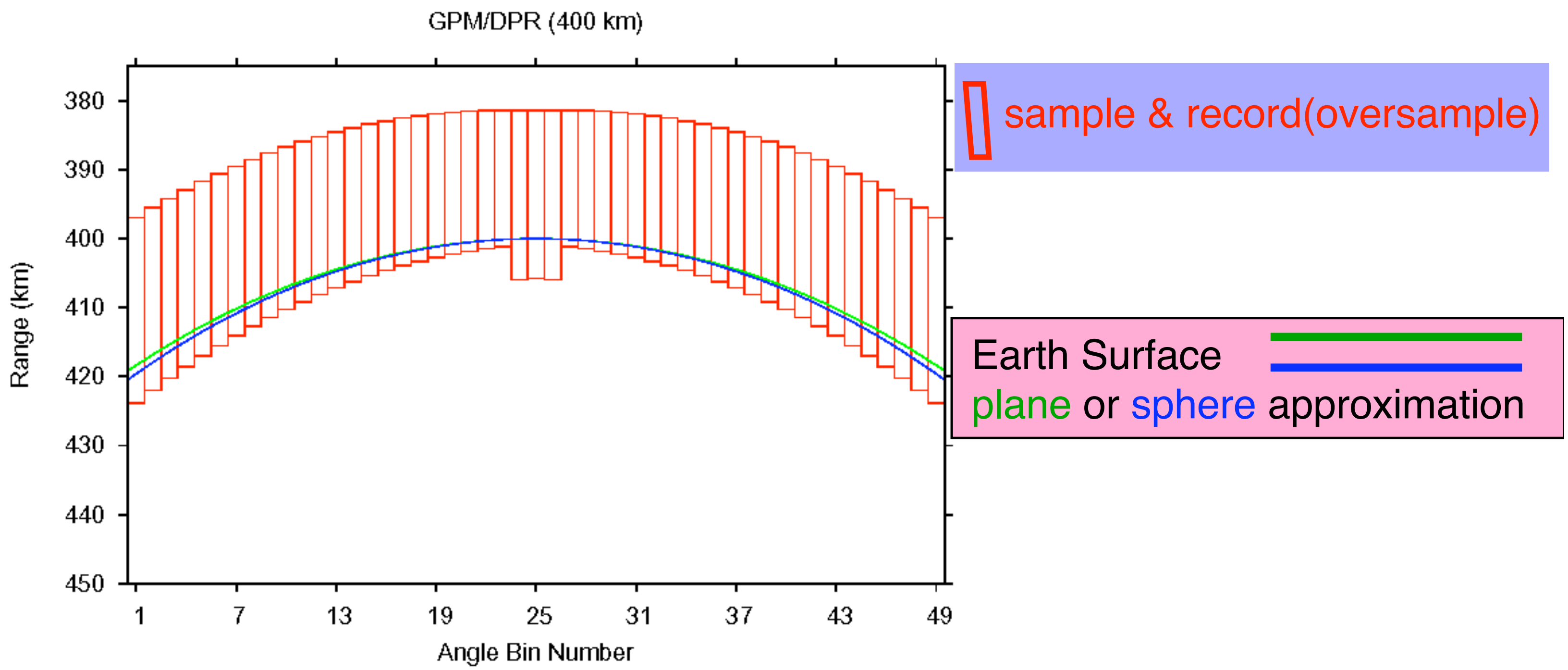
# PR vs. DPR (Radar Observation Volume)

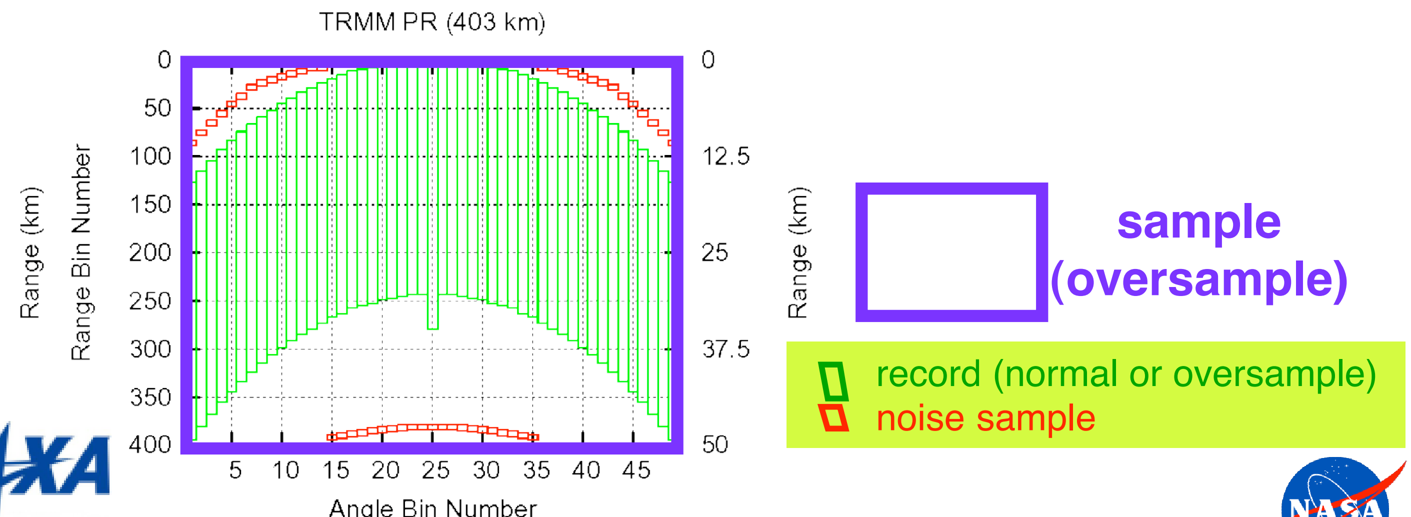



Earth Surface
plane or sphere approximation

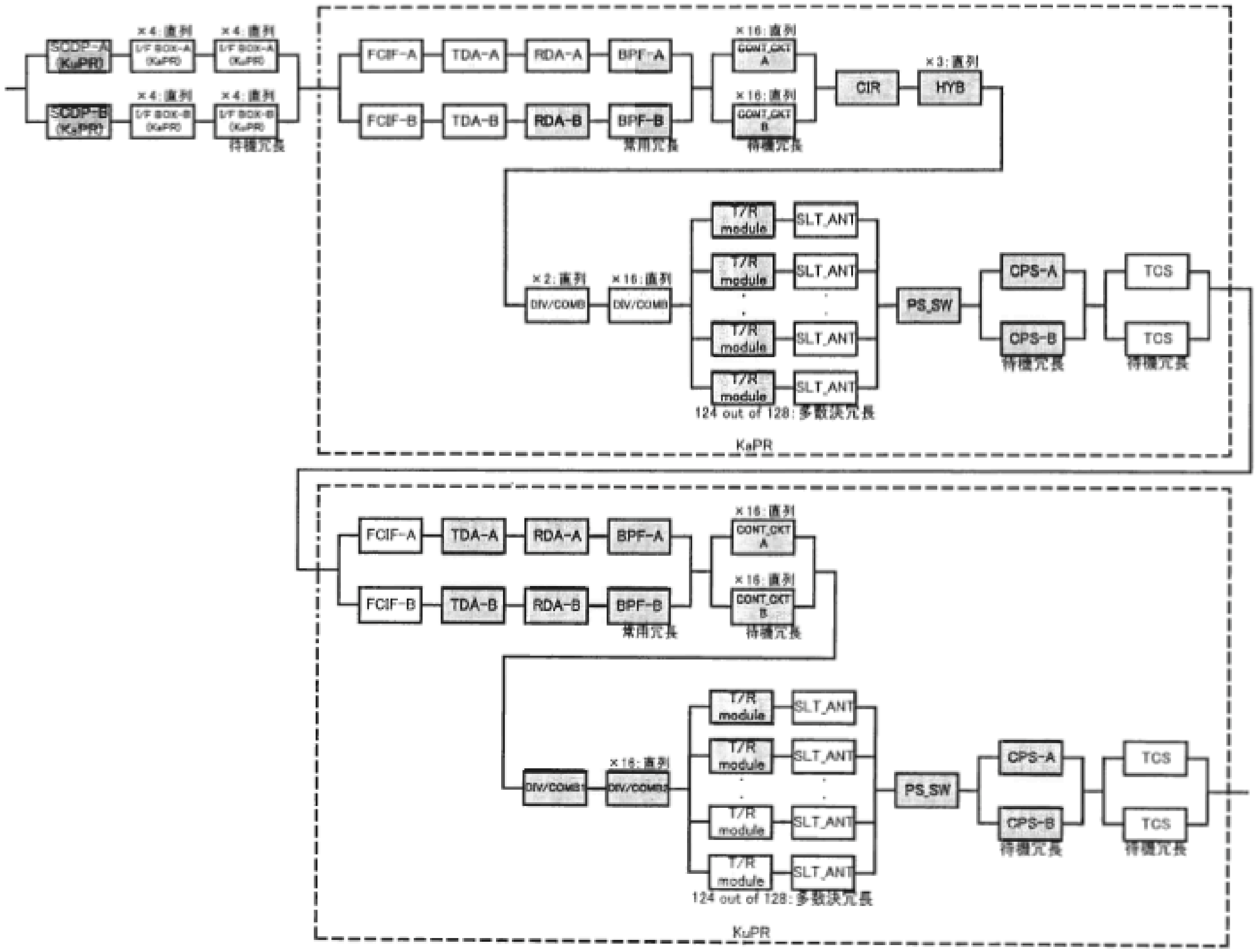


# PR vs. DPR (Radar Echo Sampling)



# DPR Probability of Success




| Sub-System | Reliability |
|---|---|
| SCDP+ IF BOX | 0.963920 |
| KaPR | 0.928293 |
| KuPR | 0.923262 |
| DPR | 0.826135 |

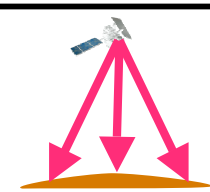
***Reliability Analyzed by parts count method. These values are the best estimations.***

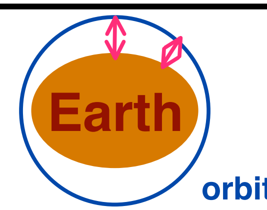
# VPRF Variable Pulse Repetition Frequency

- **What ?**
  - Transmit Pulse interval (=PRI, pulse repetition interval) according to distance to a target

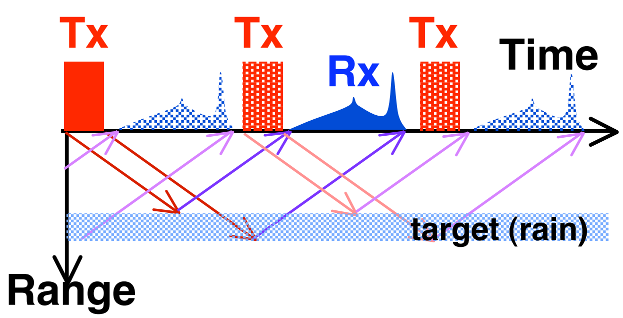
| | Same beam | Beam swings | Satellite altitude |
|---|---|---|---|
| TRMM PR | Fixed | Fixed | Fixed |
| DPR(KuPR,KaPR) | Fixed | Variable | Variable |

- **Why ?**
  - Efficient sampling for higher sensitivity
  - GPM core satellite large altitude variation, compared with TRMM





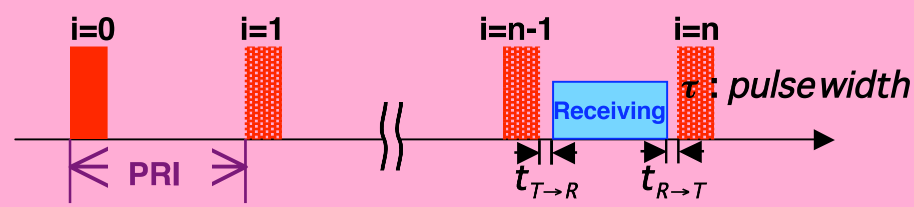

- **How ?**
  - Different timing between transmitting (Tx) and receiving (Rx)




## PRI constraint

**n: catching integer**

A pulse transmitted on time 0 is received between the (n-1) th and the n th transmission pulses, which defines a catching integer n.




$$PRI\cdot(n-1)+\tau+t_{T\to R}=t_{min}\le t\le t_{max}=PRI\cdot n-t_{R\to T}$$

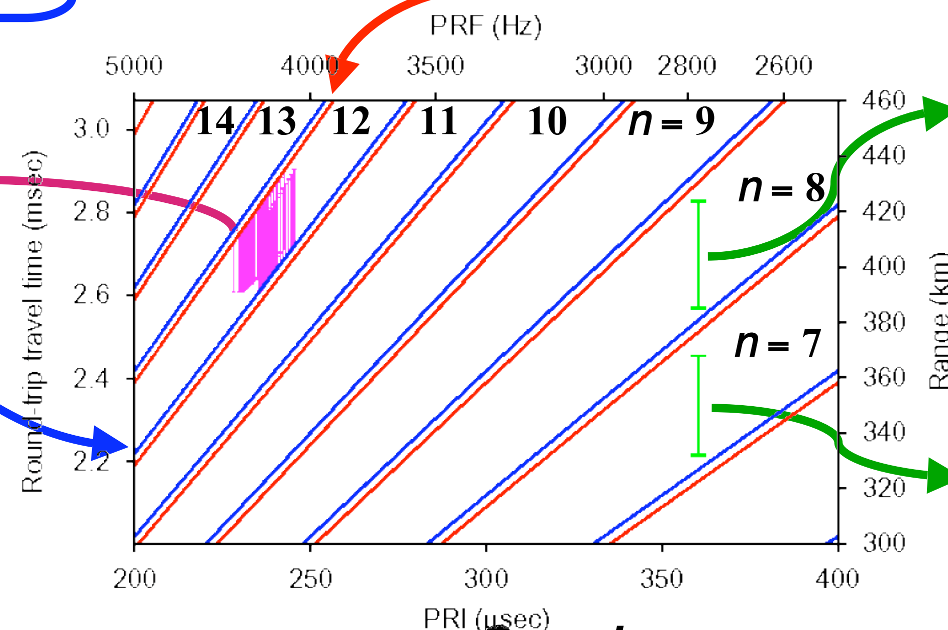
# VPRF Variable Pulse Repetition Frequency

## VPRF(GPM DPR) vs Fixed PRF(TRMM PR)

### PRI constraint

$$\underbrace{PRI\cdot(n-1)+\tau+t_{T\to R}}=t_{min}\le t\le t_{max}=\underbrace{PRI\cdot n-t_{R\to T}}$$

**KuPR (410 km)**



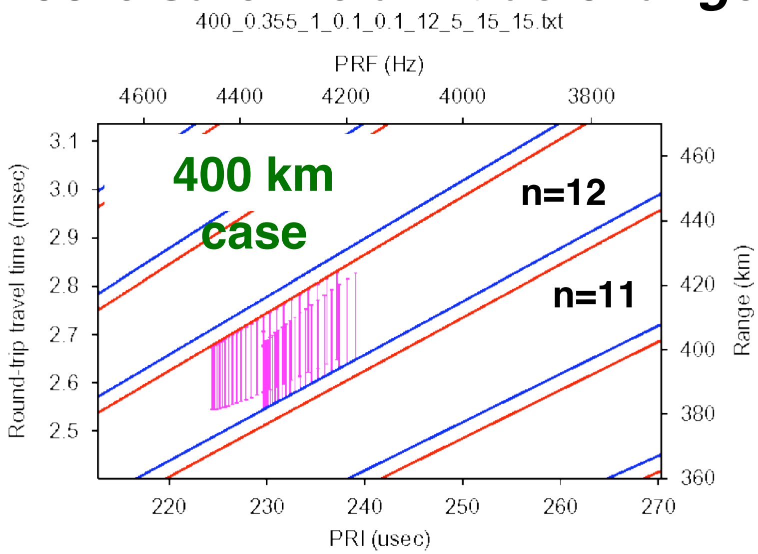

**TRMM PR (403 km)**

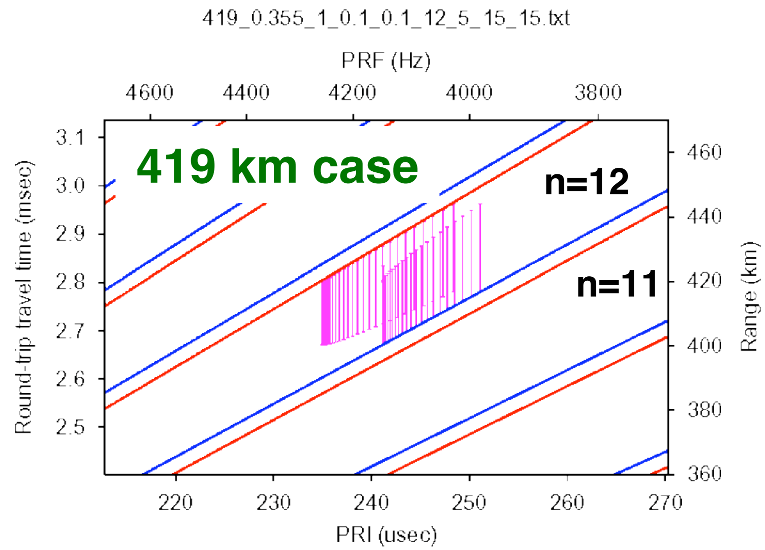
**TRMM PR (350 km)**

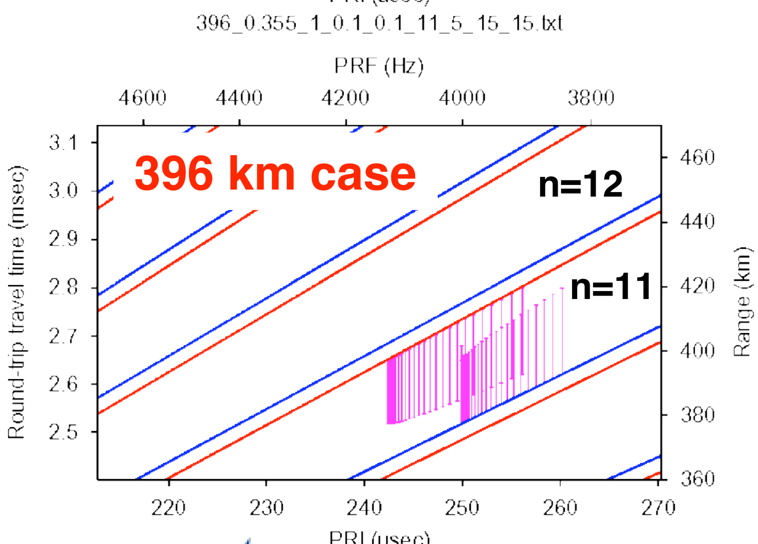
| | PRF | | Hit | Sample | Noise sample |
|---|---|---|---|---|---|
| PR | Fixed | 2776 Hz | 32 | 64 | $256\ (=64\times 4)$ |
| DPR | Variable | 3981 – 4493 Hz | 49 – 55 | 98-110 | KuPR : $720\ (=18km/250m\times 5hit\times 2)$<br>KaPR : $360\ (=18km/500m\times 5hit\times 2)$ |

# VPRF Variable Pulse Repetition Frequency

## *GPM core satellite altitude change effect*




Satellite altitude 396 km

Catching integer: n
from 12 to 11

PRF :decrease means less sensitivity

# Definition of Minimum Detectable Rainfall Rate

**(1) The minimum detectable reflectivity is calculated as following:**

**[signal power] = [total receiving power] – [noise power]**

**Std of the total receiving power: $\sigma t = 5.57/\mathrm{SQRT}(N) = 0.557$ dB ($N$=100)**

**Std of the noise power: $\sigma n = 5.57/\mathrm{SQRT}(M) = 0.178$ dB ($M$=976)**

**where, *N* is the averaging sampling number, and *M* is the noise sampling number**

**The mean noise power under the condition of Te=323 K (50ºC), Ta=290 K (17ºC), Antenna Efficiency = 0.95, Spacecraft altitude = 419 km is derived from the hardware characteristics (Tx power, antenna gain, noise figure, loss, etc), that is 16.92 dBZ (for KaPR, 500 m resolution).**

**(2) Considering the judgment on the presence of rain using the 2-σ threshold in a no-rain case, the mean total receiving power is expressed by**

$$16.92 \text{ dBZ} + 2 \times \mathrm{SQRT}(\sigma t^2 + \sigma n^2) = 18.09 \text{ dBZ},$$

**and, the mean signal power is presented by**

$$10^{1.809} - 10^{1.692} = 15.21 \text{ (in real number)} \rightarrow 11.82 \text{ dBZ}$$

**(3) The minimum detectable rainfall rate defined at the echo top height (not included rain attenuation) is calculated using a Z-R relationship ($Z=200R^{1.6}$) for weak rainfall.**

**11.82 dBZ → 0.20 mm/hr**

# Beam Matching Requirement

*KuPR and KaPR beam co-alignment requirement*

- *Pre-launch co-alignment allocation*
  - *Cross track direction : 0.35 degree*
  - *Along track direction : 0.35 degrees*

- *Post-launch co-alignment allocation*
  - *On-orbit Requirement : 1 km (0.14 degrees)*

**These requirements are still under review.*

# Beam Matching Allocation



## Pre-Launch Co-Alignment Budget (arc-minutes)

| ERROR SOURCE | RX (ROLL) CROSSTRACK | RY (PITCH) ALONGTRACK | RZ (YAW) |
|---|---|---|---|
| **RANDOM ERRORS:** | | | |
| A. S/C CONTRIBUTIONS (Relative between KuPR and KaPR Reference Cubes): | | | |
| THERMAL DISTORTION | | | |
| LAUNCH SHIFT | | | |
| MEASUREMENT ACCURACY | | | |
| STRUCTURAL DYNAMICS | | | |
| **TOTAL S/C CONTRIBUTION** | 3.000 | 3.000 | 3.000 |
| B. KuPR INSTRUMENT INTERNAL : | | | |
| THERMAL DISTORTION | | | |
| LAUNCH SHIFT | | | |
| CENTER BEAM MEASUREMENT ACCURACY | | | |
| PHASE ERROR | | | |
| **TOTAL KuPR INSTRUMENT INTERNAL** | 8.000 | 8.000 | 7.000 |
| C. KaPR INSTRUMENT INTERNAL : | | | |
| THERMAL DISTORTION | | | |
| LAUNCH SHIFT | | | |
| CENTER BEAM MEASUREMENT ACCURACY | | | |
| PHASE ERROR | | | |
| **TOTAL KaPR INSTRUMENT INTERNAL** | 8.000 | 8.000 | 7.000 |
| **BIAS ERRORS:** | | | |
| SPACECRAFT GRAVITY RELEASE | 1.000 | 2.000 | 1.000 |
| INSTRUMENT GRAVITY RELEASE | 1.000 | 1.000 | 1.000 |
| KaPR/KuPR PLACEMENT BIAS | 4.000 | 4.000 | 4.000 |
| Sum of Bias Errors: | 6.000 | 7.000 | |
| **TOTAL RANDOM ERRORS:** | | | |
| A TOTAL S/C CONTRIBUTION | 3.000 | 3.000 | |
| B KuPR INSTRUMENT INTERNAL | 8.000 | 8.000 | |
| C KaPR INSTRUMENT INTERNAL | 8.000 | 8.000 | |
| RSS of Random Errors | 11.705 | 11.705 | |
| **SUM OF RANDOM AND BIAS ERRORS** | 17.705 | 18.705 | |
| **ALLOCATION** | 21.000 | 21.000 | |
| **MARGIN** | 3.295 | 2.295 | |
| | phase correction | time correction | |

## Post-Launch/On-Orbit Co-Alignment (arc-minutes)

| ERROR SOURCE | RX (ROLL) CROSSTRACK | RY (PITCH) ALONGTRACK | RZ (YAW) |
|---|---|---|---|
| **RANDOM ERRORS:** | | | |
| A. S/C CONTRIBUTIONS (Relative between KuPR and KaPR Reference Cubes): | | | |
| THERMAL DISTORTION | | | |
| STRUCTURAL DYNAMICS | | | |
| **TOTAL S/C CONTRIBUTION** | 1.000 | 1.000 | 2.000 |
| B. KuPR INSTRUMENT INTERNAL : | | | |
| THERMAL DISTORTION | | | |
| PHASE ERROR | | | |
| **TOTAL KuPR INSTRUMENT INTERNAL** | 2.000 | 3.000 | 3.000 |
| C. KaPR INSTRUMENT INTERNAL : | | | |
| THERMAL DISTORTION | | | |
| PHASE ERROR | | | |
| **TOTAL KaPR INSTRUMENT INTERNAL** | 2.000 | 3.000 | 3.000 |
| D. ON-ORBIT BEAM MATCHING ERROR | | | |
| BEAM MATCHING ACCURACY BETWEEN KuPR &KaPR | | | |
| CT PHASE TUNING ACCURACY | | | |
| **TOTAL BEAM MATCHING ERROR** | 2.000 | 1.000 | 0.000 |
| **BIAS ERRORS:** | | | |
| SPACECRAFT GRAVITY RELEASE | 0.000 | 0.000 | 0.000 |
| INSTRUMENT GRAVITY RELEASE | 0.000 | 0.000 | 0.000 |
| KaPR/KuPR PLACEMENT BIAS | 0.000 | 0.000 | 0.000 |
| Sum of Bias Errors: | 0.000 | 0.000 | |
| **TOTAL RANDOM ERRORS:** | | | |
| A TOTAL S/C CONTRIBUTION | 1.000 | 1.000 | |
| B KuPR INSTRUMENT INTERNAL | 2.000 | 3.000 | |
| C KaPR INSTRUMENT INTERNAL | 2.000 | 3.000 | |
| D ON-ORBIT BEAM MATCHING ERROR | 2.000 | 1.000 | |
| RSS of Random Errors | 4.000 | 5.000 | |
| **SUM OF RANDOM AND BIAS ERRORS** | 4.000 | 5.000 | |
| **RSS OF RX AND RY DIRECTIONS =** | 6.403 | | |
| **ON-ORBIT REQUIREMENT (1 Km) =** | 8.447 | | |
| **MARGIN** | 2.043 | | |

SAMPLE

*These allocations are under review.

**Day 1 - December 6, 2005**

**Location: NASA GSFC B16W-N76/80**

| Time | Section | Event | Presenter |
|---|---|---|---|
| 8:30 AM | | Logistics & Announcements | Durning |
| 8:35 AM | 1 | Introduction | Durning/Ho |
| 8:45 AM | | Charge to Review Team/RIDs: Purpose & Review Criteria | Ho |
| 8:55 AM | | HQ Overview | Neeck |
| 9:10 AM | 2 | GPM Mission Overview | Durning |
| 9:55 AM | 3 | Science Requirements | Hou |
| **10:25 AM** | | **Break** | |
| 10:40 AM | 4 | Mission Requirements | Bundas |
| 11:10 AM | 5 | Mission Architecture | Bundas |
| **11:55 AM** | | **Lunch** | |
| 12:55 PM | 6 | Systems Engineering Processes | Bundas |
| 1:40 PM | 7 | System Safety and Mission Assurance | Toutsi |
| 1:55 PM | 8 | External Interfaces | Hwang |
| 2:10 PM | 9 | Dual Precipitation Radar (DPR) Overview/Requirements | Woodall |
| **2:55 PM** | | **Break** | |
| 3:10 PM | 10 | GPM Microwave Imager (GMI) Overview/Requirements | Flaming/Bidwell |
| 4:10 PM | 11 | H-IIA Launch Vehicle | Woodall |
| 4:30 PM | | Review Team Caucus | |
| **4:40 PM** | | **End of Day 1** | |